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State Geological and Natural History Survey
BULLETIN No. 29

THE QUATERNARY GEOLOGY

OF THE NEW HAVEN REGION, CONNECTICUT

By
FREEMAN WARD, Ph.D.
State Geologist and Professor of Geology,
University of South Dakota

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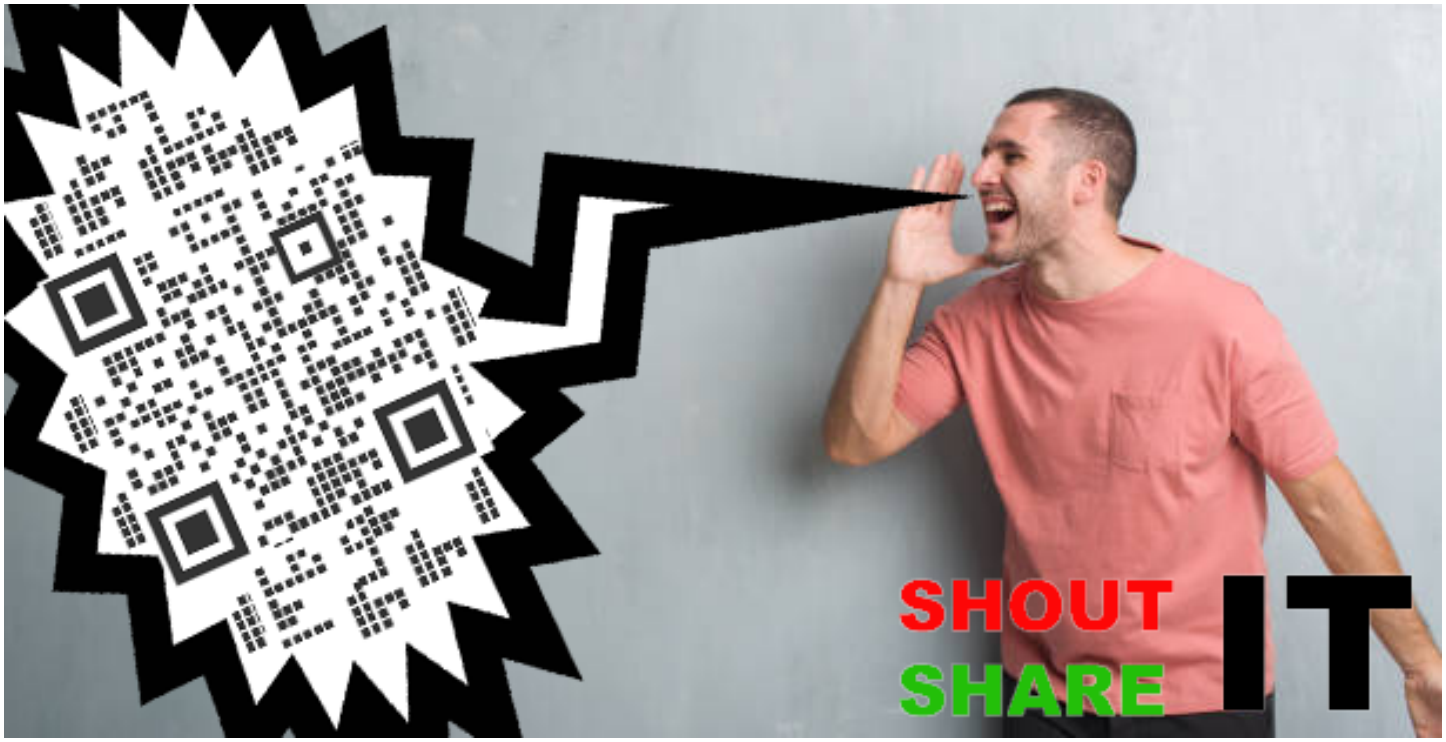
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Water-Supply Paper 397. Ground Water in the Waterbury Area, Connecticut: by Arthur J. Ellis, under the direction of Herbert E. Gregory.

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HARTFORD
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By
FREEMAN WARD, Ph.D.
State Geologist and Professor of Geology,
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INTRODUCTION.

Among the papers listed in the Bibliography of Connecticut Geology (State Geological and Natural History Survey Bulletin 8, 1907) are many relating to glaciation. Most of them deal with Connecticut as a whole or with principles illustrated by glacial phenomena within the State. The present report is the result of the study of a relatively small area and is based on field observations made in 1909 and 1910, supplemented by material taken from a thesis presented to Yale University.

The work, both in field and office, has been under the direction of Professor Herbert E. Gregory, of Yale University, to whom the writer is indebted for valuable criticism and expert advice. Acknowledgments are also due to Professor L. V. Pirsson and Professor Joseph Barrell, of Yale University, whose generous suggestions were of great benefit. The services rendered by many people who furnished valuable information concerning wells and excavations are also thankfully acknowledged.

THE QUATERNARY GEOLOGY OF THE NEW HAVEN REGION, CONNECTICUT

LOCATION.

The area described in this report is located in the south central part of Connecticut bordering Long Island Sound and extending inland. The city of New Haven and its environs are in the southern part of the area; the towns of Cheshire and Yalesville are near its northern border. The length of the area north and south is about 18 miles, and its width east and west ranges from 7 to 12 miles, the whole area comprising most of the region embraced in the New Haven sheet of the Topographic Atlas of the United States. The region belongs to the central lowland,[1] a part of Connecticut characterized by lower altitude and general lower relief than the highland area, and by the presence of the Triassic formation (sandstone, shale, and trap rocks). A small part of the highland underlain by crystalline rock is included.

TOPOGRAPHY.

VALLEYS.

As shown in figure 1 and Plate I (p. 79), the southern part of the central lowland is roughly divided into four north and south strips by the valleys of West River, Mill River, Quinnipiac River, and Farm River. The largest valley, the Quinnipiac, merges with the West and Mill valleys in the flat New Haven plain, which stands but 40 to 60 feet above sea level. Similarly,

[1] Rice, W. N., and Gregory, H. E., Manual of the geology of Connecticut: Connecticut Geol. and Nat. Hist. Survey Bull. 6, p. 17, 1906.

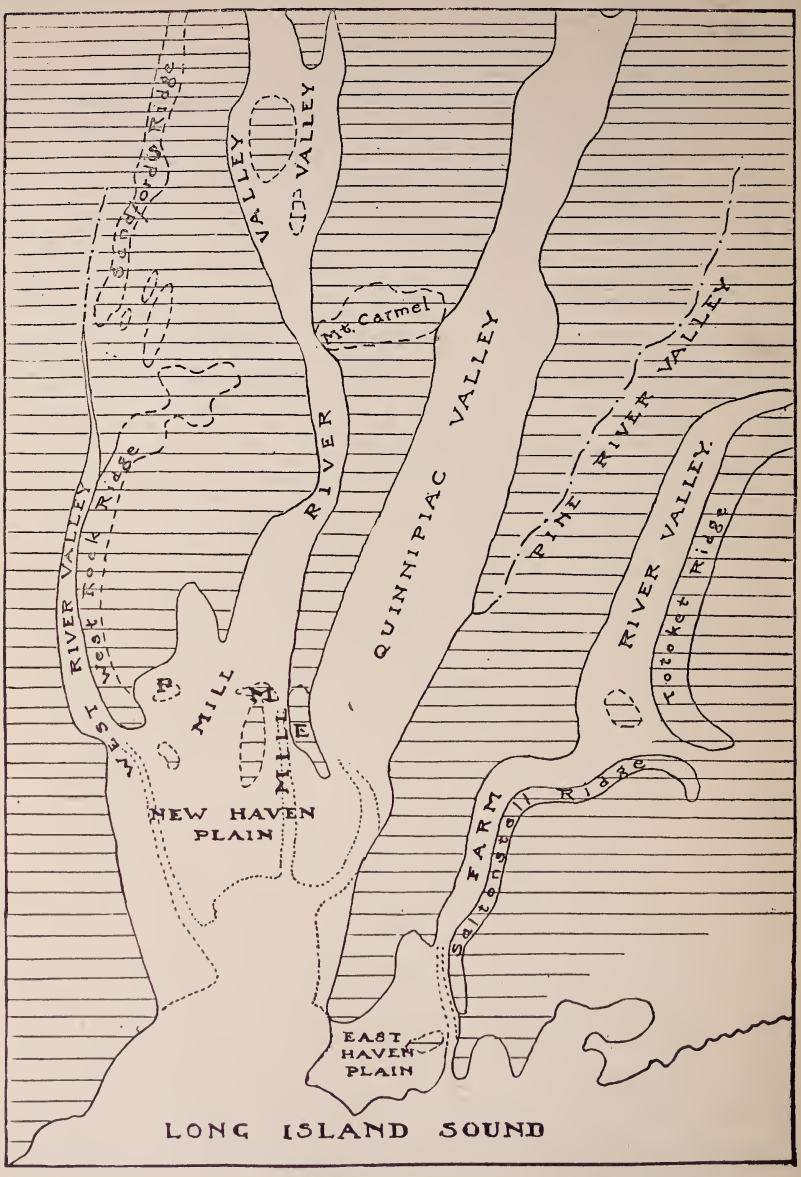


FIG. 1. Map of uplands and lowlands in the New Haven region.

Farm River valley at its lower extremity spreads out into the East Haven plain. All these valleys carry tidewater streams for at least 2 miles, and the Quinnipiac River is affected by the tide for a distance of about 8 miles, to a point beyond North Haven. Inland from the tidal limit the floor of the Quinnipiac Valley holds its low position to a point beyond Yalesville where the 100-foot contour is crossed. The other rivers have a somewhat steeper gradient. Mill River reaches the 100-foot mark at Mount Carmel, and Farm River at Totoket. West River is flowing at an elevation of 100 feet near Lake Dawson and at 200 feet a mile and a half above the lake. From this point the valley rapidly steepens, and the headwaters opposite Mount Sandford start from the 700-foot contour. The narrow valley and steep gradient of West River in the upper part of its course are to be contrasted with the broad, flat floor in the lower part of its course. The Mill, Quinnipiac, and Farm rivers have broad, flat floors throughout their entire extent. The slopes of the valleys may be expressed in the following figures based on approximate measurements: the Quinnipiac drops 100 feet in a distance of 15 miles; Farm and Mill rivers drop 200 feet in 14 miles; West River drops 500 feet in the first five miles from its source and 200 feet in the remaining 8 miles of its course. A less prominent river and valley, Pine River and its northern extension, occupy a position between the Farm and Quinnipiac valleys and flows into the Quinnipiac by the way of Five Mile Brook.

Throughout much of their extent these valleys are more or less terraced.

RIDGES.

The ridges and uplands shown on the map (fig. 1) include the prominent topographic features: West Rock Ridge, Salstonstall Ridge (Pond Rock), Totoket Ridge, East Rock, and Mount Carmel.

Starting at Westville (New Haven), West Rock Ridge extends northward beyond the New Haven area. For about 6 miles in the lower part it lies in a broad curve which is connected by several small ridges with a similar ridge to the north having

Mount Sandford for its highest point. The southern end of West Rock Ridge (known locally as West Rock) rises abruptly from the New Haven plain to a height 405 feet above sea level. North of West Rock the ridge has a sharp cliff-like front facing West River valley and a gentle slope to the east. Its elevation increases; a height of 485 feet is reached near Lake Wintergreen, 670 feet near Bethany Notch, and 700 feet beyond the notch. The ridge of which Mount Sandford is a part presents a steep front to the east, rises abruptly 450 feet above the contiguous valley floor to the north, and merges into the highland to the west. Mount Sandford, which is not only the highest point on this ridge but in the whole area, attains an altitude of 920 feet above sea level. The highest ridge between West Rock Ridge and Mount Sandford reaches a height of 820 feet.

Saltonstall and Totoket ridges, rising abruptly from the Farm River valley, are arclike in form with chords about 5 miles long. Saltonstall Ridge is 220 feet in elevation at its southern end (Beacon Hill), 240 feet at about its middle point, and 245 feet near its northern end. Totoket Ridge has an elevation of 340 feet near North Branford and rises gradually toward the north to 600 feet near Northford. Like West Rock Ridge, Totoket presents a steep front to the west and a gentle slope to the east. On Saltonstall Ridge the slopes are more nearly uniform both east and west.

On the divide that separates the Mill and Quinnipiac valleys are two prominent topographic features, Mount Carmel and East Rock. The waters of these two valleys are not more than three-quarters of a mile apart at a point about a mile and a half from their mouths, but the intervening divide is the abruptly rising East Rock Ridge which has a maximum height of 359 feet above sea level. East Rock and its companion elevations, Mill Rock and Pine Rock, form an interrupted transverse ridge with a general east and west trend, unlike most ridges of this region. Mount Carmel is another transverse ridge and is not only more massive than East Rock Ridge but is more than twice as high — 737 feet. It spans the distance between Quinnipiac River and Mill River which are here nearly three miles apart.

A, Hills rounded by glacier. Looking northwest towards eastern portion of Mount Carmel, Conn., across *roches moutonnées* covered with 1 to 4 feet of till.

B, Trolley cut near Fort Hale Park, New Haven, Conn., showing till in section. (See analysis 1, p. 15; sample taken to right of big bowlder.)

UPLANDS.

Land averaging from 100 to 400 feet in height, characterized by broad, gentle slopes rising from the valleys, makes up most of the New Haven area. Examples of such uplands are found on the divide between East Rock and Mount Carmel, in the district north of Mount Carmel, on the slopes bordering West Rock, Sandford, and Totoket ridges, in the uplands north and south of Wallingford, and in the highland area bordering West River valley on the west. The upland area is quite well drained by small streams and brooks, the largest of which is only a few miles long. A few lakes and many small swamps dot the slopes, hollows, and valley floors. Along the coast as well as on the lower flats of the rivers are wide expanses of salt marsh.

One feature common to all ridges and hills is the smoothness of their profiles. No pointed peaks or saw-tooth ridges exist, and although some of the ridges present steep cliffs on one side, their tops are always rounded. Plate II, *A*, shows the undulating, rounded appearance of the hills and ridges of this part of Connecticut. (See also the smooth profile of West Rock Ridge, as shown in Plate III, *B*.)

GLACIAL DEPOSITS IN GENERAL.

Quaternary time, the last great period of geologic time, was characterized by the presence of ice sheets over many lands within the Temperate Zone. Early Quaternary time is, therefore, often spoken of as the "Glacial Period" or the "Ice Age," and the time which has elapsed since the retreat of the glaciers as "postglacial." In geologic terms the glacial period is Pleistocene time and postglacial is Recent. The entire State of Connecticut was buried under ice during the Pleistocene, and these ancient glaciers are responsible for much of the natural scenery of the State.[1] In the central lowland, glacial deposits are extensive

[1] It is not within the scope of this report to discuss the work of glaciers or causes of glacial periods. For general discussion readers are referred to standard text books. For glaciation in Connecticut see Rice, W. N., and Gregory, H. E., Manual of the geology of Connecticut: Connecticut Geol. and Nat. Hist. Survey, Bull. 6, pp. 225-259, 1906; and Gregory, H. E., Bibliography of the geology of Connecticut: Idem, Bull. 8, Nos. 29, 31, 33, 38, 41, 56, 58, 64, 1907.

and assume a variety of forms. They are described as *drift* or *glacial drift,* which includes all of the loose rocky débris (sand, gravel, clay, bowlders) moved and deposited by glaciers of Pleistocene time. The drift consists essentially of two types of materials called *till* and *stratified* (or modified) *drift.*

Till is that part of the drift which has been carried on and in the ice of the glacier or pushed along beneath it, coming to rest only when the ice melts; it is ice-carried and ice-laid material. Till, therefore, is dropped in irregular heaps and is not arranged in layers, beds, or strata. Stratified drift is that part of the drift which has been carried by the waters of the melting glacier ice, just as sand and gravel are carried by streams and floods; it is water-carried and water-laid material. The suspended matter comes to rest whenever the velocity of the moving water is checked. Stratified drift is dropped in a regular manner, forming layers, beds, or strata.

In most parts of the south-central lowland of Connecticut these two portions of the drift are distributed with some regularity (see Pl. I, p. 79). Stratified drift is usually found in the broad valley portions of the area and till on the uplands.

As its load was dropped wherever the ice melted, and as the glacier is known to have overridden the whole country, till could have been deposited on hill or valley; stratified drift, however, could not be formed everywhere, as sorting and deposition of its materials would depend on water, which moves along certain runways, accumulates in certain basins, and behaves in a regular manner according to the laws of fluids. The load, therefore, that water carries could be deposited only at such places as the water is able to reach. Hence, the great part of a glacial problem is to explain the position and character of the stratified accumulations.

TILL.

SURFACE DISTRIBUTION.

An examination of the map (Pl. I) shows that, in general, till forms the surface of the uplands. The map also shows that some places of relatively high elevation are occupied by stratified deposits, for instance,— near Westville, about a mile northwest of

Centerville, west of Mount Carmel, northwest of Brooksvale, and near Wallingford. The opposite is also true — that many of the valleys of the uplands are lined with till instead of stratified drift, though some have a narrow strip of stratified material along their floors. Such accumulations are too small to be represented on the map. Till also occurs on low knolls in the midst of valley or plain deposits, as at Beaver Hill, New Haven, and the hill half a mile east of the North Haven railroad station.

Till is commonly found covering the uplands and hilltops and spreading down the slopes until it meets the stratified deposits of the broad valleys or plains. The point of juncture is usually at the general level of the valley floor; in some instances till may reach a lower level than stratified deposits (see fig. 2, *B*). Till of bare bedrock will be found where stratified drift is absent.

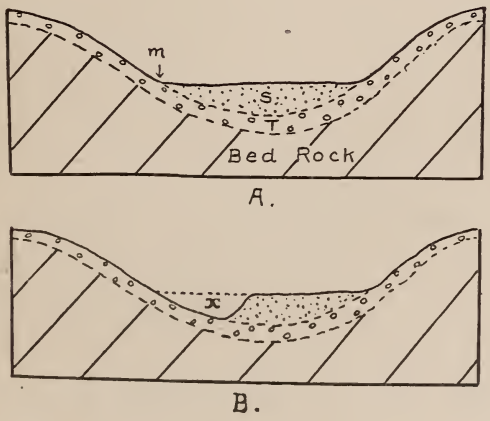


FIG. 2. Cross sections showing: *A*, Position of till with relation to stratified drift. *B*, The same after erosion.

EXTENT BENEATH THE SURFACE.

The entire extent of till is not represented by its total surface area, for in many places instead of stopping abruptly upon meeting stratified drift it passes on beneath (see figs. 2, 6, 7). Till, in turn, usually rests upon bedrock, although in a number of places it is not found beneath stratified drift. Again, it is occasionally found to contain small layers or lenses of stratified drift.

The depth of till ranges from a thin layer to 100 feet, possibly in some places, which have not yet been found, being even thicker. At fully 60 per cent. of the places examined till was found to be 10 feet deep or less, and 10 per cent. of the places showed a depth greater than 40 feet. It is common to find hill after hill upon which the till mantle ranges from 1 to 4 feet in thickness, and such hills may be described as *roches moutonnées* covered with a thin layer of till (see Pl. II, *A*).

The accepted theories of the habits of glaciers explain the main facts so far outlined. A glacier, moving over the land, scraping and gathering débris on all sides from the rocky floor over which it passes, carries along its load of mixed material until the ice melts, when the load is dropped, without sorting, on upland and lowland alike and thus forms the general till mantle. The débris is not dropped uniformly everywhere, primarily because the ice was irregularly loaded, also because the rate of the melting of the ice varies locally. Hence the depth of the till varies. Upon melting and receding, the ice forms an abundant supply of water which passes over the till, erodes, transports, and modifies it. The load so gathered by the waters and spread out in a regular manner along the main trunk channels is known as stratified drift. It may be deposited on top of till which lines the channels, or the till may be eroded or entirely removed by the streams and stratified drift laid directly on the bedrock. Hence it is that till is spread widely over the land and stratified drift rests upon it in certain places.

Normally the surface outcrops of till are at a higher elevation than those of stratified drift; but along some portions of the valleys which hold stratified drift, till has a lower position at the surface than stratified drift, as shown in figure 2. Stratified drift has naturally been spread over the valley to a uniform height in the first instance, as is indicated in figure 2, *A*. Erosion subsequent to deposition has removed a portion of this material, starting at the side, *m*, and stripping back the looser stratified drift from the relatively more resistant till. In figure 2, *B*, the portion, *x*, has been removed so that the lowest part of the valley is till instead of stratified drift.

Wherever stratified drift is found within the main body of till

— that is, a layer of sand only a few feet thick with till below and above — it does not necessarily mean that the first till was laid down as described above, then a thin layer of sand spread out, followed by a second overriding of the ice with a second load of till; for these sand layers are too thin, lenslike, and local, and the sand is not packed solidly enough to give evidence of the overriding of a glacier. It must have been true that during the time the till was being dropped there was always a certain amount of water present. The glaciers of the present day, continually melting in both their advance and retreat, support this conception. So, if the conditions are right, some stratified drift may be intermingled with the accumulating till in small amounts. The most favorable of such conditions are found along the thinning margin of a waning glacier. Here, by the melting of the retaining ice the one-time englacial drift has become superglacial drift, which ordinarily rests on ground moraine, but in some instances is separated from it by sheets of thin ice. This ice would most likely be spongy enough to allow water laden with fine débris to sift through and would in time be replaced by a layer of sand bounded both above and below by till. A less probable condition might exist where seams, shear planes, or joints have developed in the till because of differential movement due to overriding. These planes might later serve as paths along which water could move and either work over the material in place or introduce fine detritus from without, or both, thus forming a thin sheet of sand within the main body of till. Other explanations for the appearance of small lenses of stratified drift within till are possible.

COLOR.

The color of till is either brown, yellowish, ochre-brown, or some shade of dark or brownish red, a color similar to or the same as that of the red sandstone of the New Haven region. In places where both of these colors are present in section, the yellow-brown portion is always uppermost and grades downward to the red-brown through a transition zone usually less than a foot wide. The plane of separation is not marked by weathering or erosion channels or other evidences of a time interval. The color

of till determines the color of the soil — yellowish, less commonly reddish, or darker shades when mixed with humus. The surface color of the till, then, is dark brown, very often with a yellowish, less commonly with a reddish, tone. But color can not be used as a means of distinguishing till from stratified drift, for both may have similar tones.

The colors of till can best be explained by considering the process of weathering. The red color of the lower till and of the red sandstones and shales is due to the presence of numerous small stains and coatings of ferric oxide — the mineral, hematite — which is reddish in color. On weathering, hematite changes to hydrated ferric oxide — the mineral, limonite (yellow ochre) — which is yellow-brown in color. It is believed that till was originally reddish in color from top to bottom and that in the normal process of weathering the upper portion was the first to change to yellow, the depth of the change depending on the ease of weathering and the time involved since the process started. As a result, the thickness of yellow-brown till overlying red-brown varies, and a sharp line of division can not be drawn. The fact that yellow till is less compact than red till is due to the loosening effect of weathering. The inference that red till is derived from red rock is borne out by field evidence. In till that is only a short distance from the sandstone area the color distinction between the upper and lower portions is not well marked, and in till well within the area of crystalline rocks the color distinction does not exist.

Two other less satisfactory explanations of the two colors follow: (1) The lower red-brown material is considered as ground moraine and the upper yellow-brown as englacial drift. The ground moraine consists largely of local material — red sandstone and shale. The englacial drift consists of a great variety of rock fragments, some local and some foreign, producing a mixture giving to the whole a neutral yellow tone. The overlying englacial material is also less compact than the underlying ground moraine. But the materials of the two portions of till are not enough different to make this theory plausible. (2) The two colors are taken to represent two periods of glaciation, the red-brown till accumulating first and the yellow-brown last. The objection to this theory is that wherever the two are seen

together there is no independent evidence of a time interval. It is, of course, possible that there were two advances of the ice. If so, the interval between them must have been short, or if it was long then the second advance removed all records of the interglacial interval, at least at the places where the two portions are now exposed to view.

STRUCTURE.

The structure of till is very characteristic. It consists of large and small fragments indiscriminately mixed. There is no stratification. In some places, however, till exhibits indistinct, parallel bands, consisting of overlapping, lens-shaped, layer-like groupings of the material in a roughly horizontal position. The name *laminated till* has been given to till with this structure (see fig. 3). Although the structure planes are not always apparent in a fresh exposure, a few days' weathering may bring them out; but even in the best exposures they may not be distinct enough to be seen

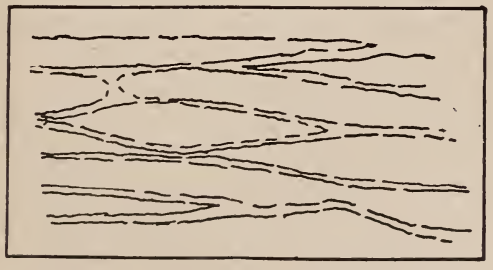


FIG. 3. Cross section of laminated till. (Natural size.)

beyond the distance of a few yards. This structure is probably the same as that described by Geikie.[1] And the term "foliation" used by Chamberlain and Salisbury[2] probably refers to the same thing.

Such till in this region is commonly if not always reddish in color and quite sandy: it is very compact and has a rough cleavage parallel to the general trend of the lamination. If both yellow-brown and red-brown till are present in section it is the red

[1] Geikie, Archibald, Textbook of geology, 4th ed., p. 547, 1903.
[2] Chamberlain, T. C., and Salisbury, R. D., Geology, vol. 3, p. 342, 1906.

that is laminated. Lamination was observed at only six or eight localities, all near New Haven, but since this structure never appears at the surface it may be present in many other places.

The parallelism and extremely compact make-up of the laminae can satisfactorily be accounted for only by the pressure of overriding ice. The lenslike form of the bands, their small extent, and their overlapping show that this structure has been imposed on till and is not a regular feature of deposition. The glacial movement indicated by this structure was not probably a country-wide re-advance of the ice, but only a minor movement due perhaps to seasonal changes or to local differential shifting.

The structure of till is thus seen to be radically different from that of stratified drift and is the chief means by which the two are differentiated.

TEXTURE.

The term, texture, has reference to the sizes of the various particles, the proportion of each size present, their shape, and the manner in which they are packed. Till consists usually of stones, pebbles, and bowlders held in a fine-grained and clayey matrix and on this account is often called bowlder clay. In many parts of the United States one prominent difference between till and stratified drift is the clayey nature of the one and the sandy nature of the other. Although some clayey till is found in southern Connecticut much of it has a decidedly sandy matrix. This makes the till feel gritty rather than smooth to the touch. Roads passing through such till are sandy in dry weather and but slightly sticky in wet weather. At Gaylord Farm the till is coarse-textured enough to be successfully used as a sewage filter, and it could be similarly used in many other places. The mechanical analyses listed in the table below will show this point more exactly. The analyses made were of materials less than 6 millimeters in diameter after all the larger fragments had been screened out; particles less than 2 millimeters in diameter were determined by the beaker method. The finest particles — silt and clay — have diameters 0.05-0 millimeter. Analyses 1 and 2 show a small quantity of clay, 3 a little more, and 4 approaches the kind of till which is generally considered as typical.

A, Glacial erratic, Judges Cave, West Rock Ridge.

B, Valley filling of stratified drift meeting the steep valley wall abruptly. West River valley and West Rock Ridge.

Mechanical analyses of till.

Diameter of particles	1. Per cent	2. Per cent	3. Per cent.	4. Per cent
6-3 mm.	7.2	3.88	.56	4.7
3-2 mm.	8.8	5.12	1.00	3.3
2-1 mm.	17.98	20.20	3.94	6.44
1-0.5 mm.	17.47	18.28	8.46	6.80
0.5-0.25 mm.	8.57	9.10	6.89	4.41
0.25-0.05 mm.	28.56	32.94	64.97	45.26
0.05-0 mm.	11.34	10.37	14.17	29.06
	99.92	99.99	99.99	99.97

Places from which samples were obtained.

1. Trolley cut near Fort Hale Park, New Haven. See Plate II, *B*.

2. Old quarry along Forest Street, near end of Oak Street, New Haven.

3. Tunnel cut, Shore Line Railroad, New Haven.

4. Cut along road near East Wallingford.

According to the table used by the Bureau of Soils[1] that part less than 2 millimeters would be classed in 1 as "Coarse Sand," in 2 also as "Coarse Sand," in 3 as "Fine Sand," and in 4 as "Fine Sandy Loam." This till is found in many places in the area and on account of its sandy nature may be confused with the stratified drift, unless more distinctive characteristics are taken into consideration.

The sandy nature of some till is readily understood from its local origin (see p. 26). A large part of the south-central lowland of Connecticut is underlain by sandstone, and since ground-up sandstone makes up so large a part of till, it would naturally be sandy.

Great variation is found in the size of fragments whose diameters are greater than 6 millimeters; practically any size may be found up to huge masses weighing many tons. The term "glacial erratics," or simply "erratics," is given to such bowlders (see Pls. II, *B*, and III, *A*). Those exceeding 10 feet in diameter are not common, but bowlders 4 to 8 feet in diameter or less are

[1] Soil Survey Field Book: U. S. Dept. Agr. Bur. Soils, pp. 17, 18, 1906.

abundant. In many places till is so charged with these large rock fragments that agriculture is seriously interfered with or even prevented. Stone fences, a common sight in till regions, represent the efforts of farmers to clear their fields. Erratics are not commonly found in areas of stratified drift.

The texture of till is compact as far as the packing of the particles is concerned, in this respect differing decidedly from the stratified drift. The sides of excavations in till will hold their position for weeks, some even for years. Excavations in stratified drift require the use of planks to prevent slumping. Till usually has more body than sand, without being noticeably solid. It may be so compact as to offer considerable resistance to a shovel and pickax, and some well diggers have even resorted to explosives. The term "hardpan" is particularly appropriate to this sort of till. Laminated till is always compact, though it may not appear so at the surface.

This compact texture may be due partly to the presence of a cement, but out of about a dozen trials to detect cement only in one instance was there a slight effervescence with cold acid. In some cases where wells were dug with difficulty in very compact till, the loosened material thrown to one side has readily "hardened" or "set" again, and though this result might be caused by the development of a cement on exposure to the weather or a reworking of the original cementing material, it is probably ordinarily due to the presence of clay which hardens on drying. Clay as a binding material has been especially effective when till has been subjected to pressure, such as that exerted by the movement of the ice. Since pressure and clay content varied, different degrees of compactness resulted. Some sandy till, however, is very compact, so that though the clay content is not necessarily the controlling factor, a small amount of it mixed in with the finest sand and silt particles may serve to bind the mass.

The shape of the particles, particularly those more than half an inch in diameter, is characteristically angular or subangular. Many of the large fragments retain the same shape they had when torn from the parent ledge; many have been modified by the wear and tear incident to transportation. The modification of shape consists of faceting, that is, development of flat planes or faces on

one or more sides due to continuous grinding or rubbing in one position. The facets are often scratched or striated. In these characteristics the fragments of till differ from those of stratified drift, which are more nearly round. A few examples have been found in the south-central part of Connecticut of rounded fragments of till whose presence and formation are explained by the advance of the glacier over a district already containing water-worn, stratified material. The shape of grains less than 2 millimeters in diameter that make up the matrix is not so angular as that of the larger pebbles. The smaller grains (2 millimeters or less) are made up almost entirely of mineral rather than rock fragments (p. 27). The mineral fragments, chiefly angular and rounded pieces and chips of quartz and feldspar, of till and of stratified drift are much alike. It is, therefore, very doubtful if the two kinds of deposits could be differentiated by the shape of grains less than 2 millimeters in diameter alone, surely not when the size is 0.5 millimeters or less. The larger fragments of rocks, however, do show differences in shape, those in till being markedly more angular than those in stratified drift.

The shape of the fragments depends on the manner in which they were carried. Those that were carried in the ice and so not ground or bruised have retained their original shape, usually angular. Those that were in the ground moraine, especially, were rubbed one over the other and against the bedrock; as a result they may lose some of their angularity — becoming subangular, striated, scratched, or faceted in the process. Fragments that have lain on the surface since the final departure of the glacier may have their angularity reduced and their striations obliterated by weathering.

COMPOSITION.

The kinds of rock in till are various. In the New Haven region about fifteen different varieties have been found, namely, sandstone— coarse, fine, shaly; trap — coarse, fine, amygdaloidal; quartzite; granite — two or three kinds; gneiss — two or three kinds; chlorite schist — two kinds. Of these, sandstone and trap predominate decidedly, not only in general distribution but also

in quantity in any one locality; and as a whole more sandstone is found than trap. Quartzite is present practically everywhere but not in any quantity. Granite and gneiss are fairly common but in small amounts. Chlorite schist is found only in till west of New Haven.

Some of the material has traveled far. Gneiss and quartzite bowlders that are known in places 20 to 50 miles to the north and east have furnished fragments, and the erratics composing Judges Cave are believed to have come from a ledge near Meriden — a fifteen-mile haul for the glacier. But by far the greater quantity of the till material is of local origin and has traveled only two or three miles; much of it only a few hundred yards. This explains the preponderance of sandstone and trap, for they make up the bedrock. The only place where granite fragments predominate is in till that rests on granite ledges in East Haven. Chlorite schist is found in till only in places where schist exists as bedrock. The change from sandstone and trap-laden till to granite or chlorite schist-laden till occurs abruptly within half a mile or less. That till is commonly of local origin is shown also by the composition of the matrix. Till resting on a sandstone ledge was found to carry bowlders and cobbles in the following estimated proportion: sandstone, 60 per cent.; trap, 35 per cent.; quartzite plus x, 5 per cent.; in the matrix, of fragments less than 6 millimeters and greater than 3 millimeters, trap made up only 6 per cent. by weight; of fragments less than 3 millimeters, it was even more rare and was entirely absent as fragments less than 0.5 millimeters. Till resting on chlorite schist not far from sandstone showed the following estimated proportions: chlorite schist, 50 per cent.; sandstone, 30 per cent.; and quartzite plus x, 20 per cent.; in the matrix of fragments less than 6 millimeters and greater than 3 millimeters only 17 per cent. by weight was sandstone; in sizes less than 3 millimeters sandstone rapidly diminished and was lacking in sizes less than 0.5 millimeters; but the chlorite schist was abundant even in sizes less than 0.25 millimeters.

A further study of the matrix showed that as the material becomes finer the rock fragments tend to disappear and the mineral fragments to increase, that is, the rock seems to be re-

duced mechanically to its simpler elements by the grinding occasioned by transportation. In this process the harder minerals persist and are segregated, and the softer ones drop out. Probably the process is not entirely a mechanical one, however, chemical solution and decomposition acting as well, and particularly is this true of feldspar, the small fragments decomposing more rapidly than the large. Fragments 0.25 millimeters in size contain chiefly quartz, some feldspar, a little magnetite, garnet, etc., and in some cases (as above) — if fine-grained rock is the local material and was originally present in large amounts — rock fragments.

The following tables illustrate the relation of the composition of till to location and size of constituents. The percentages are estimates and serve to show the relative amounts of the materials.

Till resting on sandstone ledge.

Materials / Sizes	6-3mm.	3-2mm.	2-1mm.	1-.5mm.	.5-.25mm.
Quartz	15%	35%	55%	70%	75%
Feldspar	9	20	25	25	20
Sandstone	70	41	19	5	0
Trap	6	4	1	0	
				+magnetite	5=magnetite, garnet, etc.

Till resting on chlorite formation.

						.25-.05mm
Quartz	30	47	60	67	75	80%
Feldspar	12	24	20	18	15	10
Sandstone	17	8	5	1	0	0
Chlorite Formation	41	21	15	14	10 +magnetite	9 1=magnetite, etc.

The quartz in the second table was not entirely derived from the breaking down of the sandstone. An unknown amount was derived from the chlorite schist which is threaded through with quartz. In the larger sizes a few of the quartz grains were seen still to have chlorite clinging to them.

MORAINES AND DRUMLINS.

Moraines are made up of till accumulated under special circumstances. Terminal moraines are formed by a glacier at the time when waste by melting balances the forward movement. The load of débris is constantly carried to the lowest point and dropped there, forming hills, knolls, ridges, and depressions along a band of varying width and length. The general trend represents the position of the ice front.

Associated with terminal moraines are stratified deposits called kames, formations resulting from the great volume of water produced by the melting of glacier ice. Sometimes water pours out in torrents just in front of a terminal moraine, washes and works over till to make roughly sorted mounds of gravel and sand. In many places kames indicate terminal moraines nearby which might not otherwise be prominent.

Terminal moraines in the true sense of the word are lacking in the New Haven region. In some places, however, many bowlders are segregated and though they do not have an alignment suggestive of a former ice front, they probably indicate a slight halt in the ice movement. Kames, which are usually associated with terminal moraines, occur in three places: a mile northwest of Centerville, less than a mile northwest of Brooksvale, and about a mile west of West Cheshire. Some of the fields of segregated bowlders are back of the kames, but they show no linear extension in any direction. The three sets of kames near Centerville, Brooksvale, and West Cheshire are separated by areas of excessive till accumulation. This suggests that the ice made three halts. If they are moraines they are interpreted as recessional moraines. Just north of this area, at Southington, a moraine is reported that probably represents an important halting spot of the glacier.

The segregations of bowlders in some places may be explained without assuming a halt in the retreat of a glacier, especially where they are segregated in valleys. The force of the stream working on a till deposit may be sufficient to remove only the finer materials so that the bowlders must collect along the new erosional floor of the valley.

A drumlin is a smooth, lenticular hill 50 to 200 feet high and half a mile to 1½ miles long, and is composed of till. Its longer axis is parallel to the ice movement. Of the less than a dozen drumlins seen in the New Haven region, most are in the southern part. Some cases are doubtful because not typical. The hill at North Haven and several hills west of West Haven are considered drumlins. More common are the "drumloids"— rounded elongated ridges, drumlin-like in shape but having rock cores. These few, rather obscure examples of drumlins throw no light on the theory of drumlin origin, that is, whether they are "sand bars" of an overloaded glacier, or whether they are remnants of a thick till mantle partially eroded by advancing ice — *roches moutonnées* of till.

RELATION OF TILL TO STRATIFIED DRIFT.

Till underlies stratified drift and so must be older. An exception to this usual relationship is found in two places where till overlies stratified drift — (1) between West River valley above Westville and Maltby Lakes (see fig. 4); (2) about a mile west of Mount Carmel. These formations may possibly be explained by a re-advance of the ice which resulted in a deposit of till upon stratified drift. The fact that the stratified drift beneath the till is broken and crumpled is a point in favor of this hypothesis. On the other hand, the tiny faults in the stratified drift show no definite relations to the direction of the glacier movement, and the small folds pitch in all directions. In a few places sand with till upon it is undisturbed, and the two types of deposit grade into each other. A more serious objection to the theory of glacier re-advance is the small number of places where till is known to overlie stratified drift. An explanation taking cognizance of ice gorges or dams with consequent ponding of water is more satisfactory. A temporary lake formed in the space between a dam at the lower end of West Rock Ridge in the Westville region and a dam reaching from the west end of Mount Carmel to the uplands to the west in the Mount Carmel region would make possible deposition of stratified material at high levels. On top of the stratified material, floating ice would drop a heterogeneous mixture of cobbles, bowlders, and sand heaped down in large

enough quantities to prevent sorting and hence resembling normal till. The running aground of large ice blocks — even their weight alone — would cause irregularity and a bending and twisting of the layers of stratified drift. The blocks striking bottom alone would disturb the underlying beds.

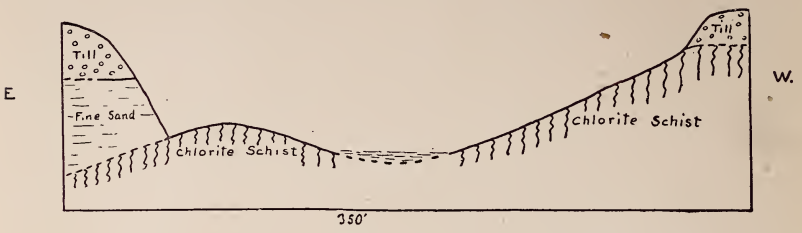


FIG. 4. Section showing till overlying stratified drift at site of dam, Marvel Wood, near New Haven.

This theory would explain the graduation between till and stratified drift already referred to. In the depression of the uplands along which lie Maltby Lakes and the pond at Westville there are spots of stratified drift, some of which are overlain by till (see fig. 4). The existence of a dam at the lower end of West Rock would help to explain the high-level stratified drift, for such a dam would naturally direct the excess water along this channel.

The absence of shore lines marking the position of the ponded water can be explained upon the supposition that the time was too short for their development or that subsequent erosion removed or obscured them.

STRATIFIED DRIFT.

DISTRIBUTION.

The map (Pl. I) shows the distribution of stratified drift. In the main it is restricted to low, flat areas — the broad valleys, the margins of the shore, and the plain on which the city of New Haven is built. In the New Haven plain the West, Mill, and Quinnipac River valleys meet at a common level. Farm River valley meets the East Haven plain at a slightly lower elevation than the New Haven plain, of which it may be considered a dis-

connected part. From this common level, and passing inland, each valley floor is seen to rise gradually and each at a somewhat different rate.

Stratified drift occupies the lower portions of the region, and it has uniformly low relief, many parts being absolutely flat. This is in contrast to the ice-laid till which in the nature of the case tends to be in irregular mounds, or whose outline, where spread evenly, is determined by the contour of the rocky floor beneath. The only parts that present steep slopes are the terrace fronts.

ORIGIN.

As compared with the haphazard accumulation of till the distribution and arrangement of stratified drift follows a definite scheme. A glacier continually wastes away by melting. The amount of water given off from a glacier even in the vigor of its largest extent is considerable, and at the time of its waning, when melting is especially pronounced, the amount produced is tremendous.

Wherever this water is in motion it is always doing active work, it cuts into the previously deposited till and washes away a certain amount which is dependent on the volume and velocity of the current. If till is lacking and bare ledge lies in its path, the water will attack it. At every step of its progress the water loosens and gathers sand, gravel, clay, etc., and carries along with it a load of this material commensurate with its strength. Thousands of small streams are formed, and as they move down the slopes neighboring streams join and carry their combined loads to the master stream. Very little if any of the material loosened by the moving waters would lodge on the hill slopes, the grade would be so steep that all the loose débris would be swept along. Likewise little deposition would occur in the minor tributaries issuing from the uplands; their streams would be too vigorous to allow it. The load would pass on to a lower level of gentler slope. This immense load of débris contributed by thousands of minor tributary streams would thus lodge in the main valleys. Some of it would move on down along the main valleys towards and into the sea, but on account of the relatively lower angle of slope the velocity of the streams would not be sufficient to remove

it all; and if part was removed more would constantly be supplied by the tributaries. Hence it is that the larger valleys and some of their tributaries become laden with stratified drift, while the hill slopes are bare or till clad.

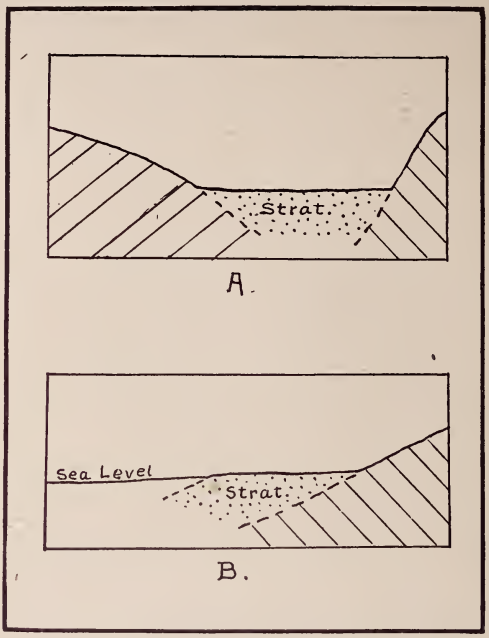


FIG. 5. *A*, Cross section of typical valley filling. *B*, Cross section of stratified drift deposit on sea margin. Typical location for swamps and salt marshes.

As stratified drift fills up depressions uniformly and is built up to a uniform height across the valley by the stream working from side to side, distributing the materials, and spreading them out, its deposits are flat and have a low topographical relief, unless modified by later action. These valley fillings meet the abrupt valley walls at a well-defined horizon (see fig. 5, *A*, and Pl. III, *B*). But where the neighboring slopes of valley or shore are gentle the boundary of stratified drift is not so sharply defined. The low, flat shore margins that have been built up by this filling process are really overlaps (see fig 5, *B*) and represent the formation on which is found so much swamp and salt marsh.

A, Kettle hole. Farm River valley about a mile north of East Haven.

B, Stratified drift.

KETTLE HOLES.

A formation that dots the valley flats is the *kettle hole,* a saucer or bowl-shaped depression without an outlet. Kettle holes are usually 5 to 15 feet deep and 50 to 100 yards in diameter, occasionally 20 to 30 feet deep and 200 to 300 yards in diameter (see Pl. IV, *A*). In the bottom of some kettles are little lakes or swampy spots. The vigorous streams flowing from the glacier carry along with the débris blocks of ice, some of which, at least in the trunk channels, may reach a size to be measured in thousands of cubic yards, or may even approach the size of a small iceberg. The large blocks soon run aground in the valleys and are covered up by sand and gravel. When the receding waters expose the stratified deposits to the air, the covered blocks melt leaving cavities whose sides slump in, making the typical kettle hole.

HIGH-LEVEL SANDS AND GRAVELS.

Some more or less isolated areas of "high-level" gravels and sands occupy positions above the general level of the valleys. Their elevation varies; some are only 100 feet above the valley or plain nearby; others are much higher, one being found 400 feet above sea level and another 500 feet. These deposits were found in the following localities: (north) west of Mount Carmel, northwest of Brooksvale, northwest of Centerville, the highlands of Westville and Maltby Lake, southeast of Wallingford. Some of the stratified deposits of Pine River Valley have this character, and though they are somewhat intermediate in position between the general valley accumulations and the high-level deposits, they belong more properly to the former.

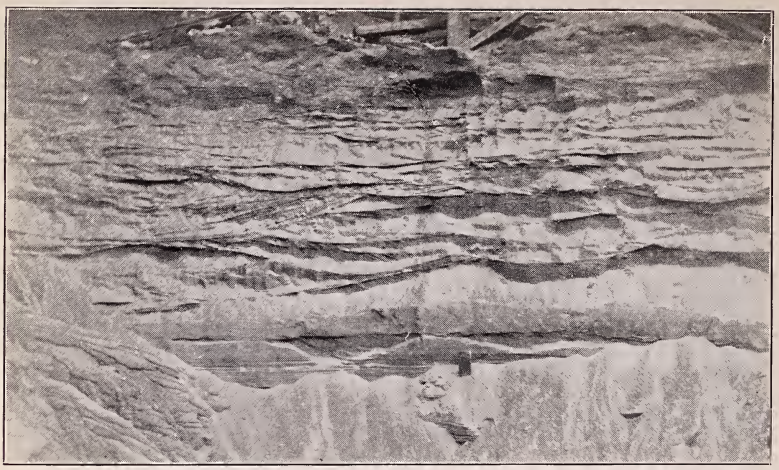
The high-level gravels and sands are best explained by assuming a ponding of the glacier waters by a temporary dam, which held the water long enough for stratified deposits to accumulate at the highest level reached. Either the glacier itself or an especially large accumulation of glacial drift blocked the drainage for a time, or floating ice clogged a channel and formed an ice "gorge." Temporary outlets at levels higher than normal would receive deposits along their courses, or local deltas would build out into this

temporary lake. Kames accumulating directly beyond the ice front might be formed at a higher level than that of the normal drainage lines. Rounded, sharp-sided hills of sand and gravel rising above the general level of the sand-floored valleys northwest of Brooksvale, about a mile northwest of Centerville, and near West Cheshire were probably formed by vigorous waters flowing from the western uplands down through the near-by gaps.

Temporary local dams would account for the other high-level stratified drift northwest of Centerville; for the sandy flat southeast of Wallingford, and for similar formations about a mile and a half south of Mount Sandford, east of Montowese, and in parts of the region south of " Hemingway Mountain " in " Fair Haven, East."

The main dams would occur at two places — one in the notch at the west end of Mount Carmel, and the other at the south end of West Rock Ridge. The Mount Carmel dam was probably an ice gorge with the glacier front not far to the north. The temporary lake formed must have been well covered with floating ice which as it melted dropped large quantities of till-like material upon the stratified deposits. Much of the material deposited in this lake must have been stripped off when the dam gave way, and the lake waters, released, rushed through the notch. The coarse bowlder deposits of stratified drift just south of the notch indicate the strength of the currents at this place.

In the region covered by a temporary lake near the West Rock dam, high-level gravels and sands and a similar layer of till-like material in places overlie stratified drift. As a result of the dam, the excess waters for the time passed out through the uplands of Westville, through the Marvelwood vicinity, south through the Maltby Lakes region, and down through what are now the flats west of Allingtown; below this point the waters diverged, part flowing southeast (where Cove River now is), part continuing southwest. As no deposits except coarse material accumulated wherever the channel was narrow and steep, such old channels are marked either by bare ledge or an abundance of bowlders. In some places along this course the stratified drift deposits are overlain by the till-like material dropped by floating ice, as already described.



A, Stratified drift, showing flow and plunge structure. Upper gravels, unconformity, lower sands. At site of Hotel Taft, New Haven, Conn. (Common brick in middle foreground gives scale.)

B, Thrust fault in stratified drift.

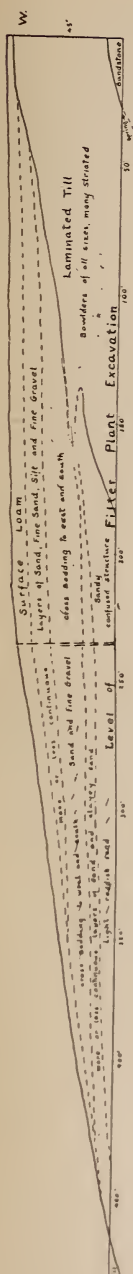


Fig. 6. Sketch section. South face of excavation at site of water filter plant south of Mill Rock, New Haven, Conn. (Vertical and horizontal scales the same.)

SUBGLACIAL DEPOSITION.

It is generally believed that waters moving beneath the glacier and ultimately issuing as subglacial streams will assort and deposit a certain amount of sand and gravel under parts of the glacier itself. Though these deposits are very likely to be obliterated by movements of the glacier at any time, under favorable circumstances they may be preserved. Their position is largely determined by the character of the undersurface of the glacier; the contour of the land or its drainage lines would exert a minimum of control. It is impossible to say to what extent this type of origin may explain the position of some of the high-level stratified drift.

STRUCTURE.

Stratified drift is definitely arranged in more or less regular beds or strata that range in thickness from a fraction of an inch to 3 feet, less commonly 4 to 8 feet, and range in extent from a few yards to a few hundred yards. Some of the layers are sharply separated from those above and below, others grade into adjacent layers; some are intricately cross-bedded, others are even-bedded, still others possess both features. Usually the deposits are horizontal or nearly so, but in a few instances have a decided dip (see Pls. IV, *B*, and V. *A*, fig. 6).

At twelve or fifteen localities the strata are warped, folded, and faulted. Some of the folds are low and gentle, 1 to 5 feet across and 2 inches to 1 foot high; others

are 10 to 15 yards across and 3 feet high; in one place an anticline and two synclines extended 75 yards with no greater height than 3 feet; in some places the fine layers are shortened by crumpling to one-half their original length. The folds may pass into undisturbed strata within a few yards. The faults are all reverse and usually have an overthrust of one-half an inch to 5 inches, in some cases 8 inches to 1 foot; one thrust is at least 25 feet and probably twice that amount. Some of the structures as above described are illustrated by figs. 7-11 and Pl. V, *B*.

As some of the gentle, broad bendings of the layers, particularly those seen in the clay beds, are near the railroad tracks, they may have been caused by the weight of the road bed and the jar resulting from traffic. Other more intricate deformations in the drift, especially those far from the railroad, are due to other causes.

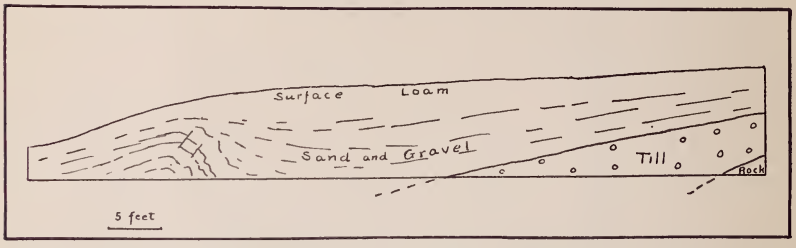


Fig. 7. Cross section showing deformations of stratified drift — faults and anticline.

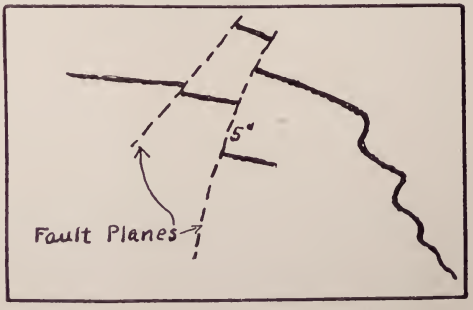


Fig. 8. Detail of section shown in Fig. 7.

The disturbed strata are of too small extent to be explained by shiftings of the earth's crust. They are believed to result from the action of ice exerted in one of the following ways: (a) glacial ice, (b) ice as icebergs, (c) ice as a continuous cover on water. (d) Another force may be gravity.

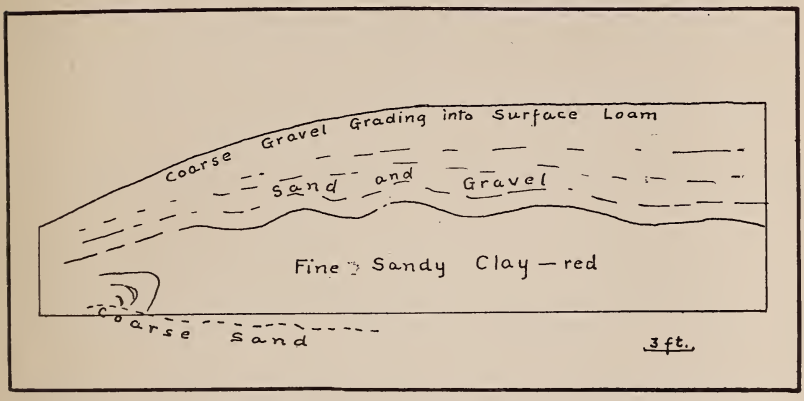


Fig. 9. Cross section showing deformations of stratified drift.

(a) After the accumulation of stratified drift the glacier may have overridden all of the deposits without removing much and without disturbing all of it, providing the glacier was not in the prime of its activity but had the feebleness of waning old age. In some regions one till layer rests upon another older one, and yet

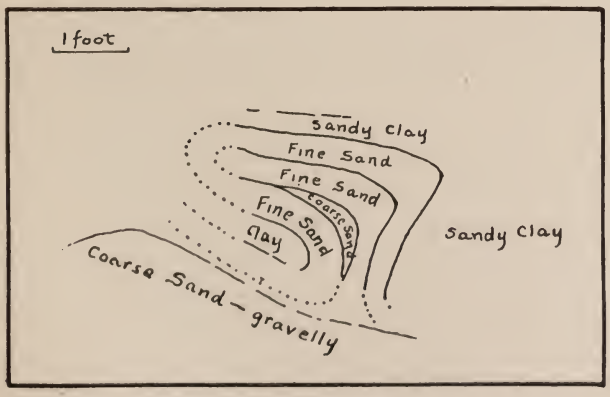


Fig. 10. Detail of section shown in Fig. 9.

the dark layer of soil capping the older till had not been removed by the glacier that brought the second load of till. Such instances make clear that a re-advance of the glacier need not disturb all the deposits it covers. But locally the ice may dig into the deposits and by its power of pushing, bend, crumple, or fault them. Some of the disturbances may have been due to the overriding of the glacier. The thrust fault shown in Plate V, *B*, involves clay in the lower portion. If the glacier had overridden the clay deposit, till must have been deposited upon it, and if till did completely or even partially cover the deposit at one time it is ex-

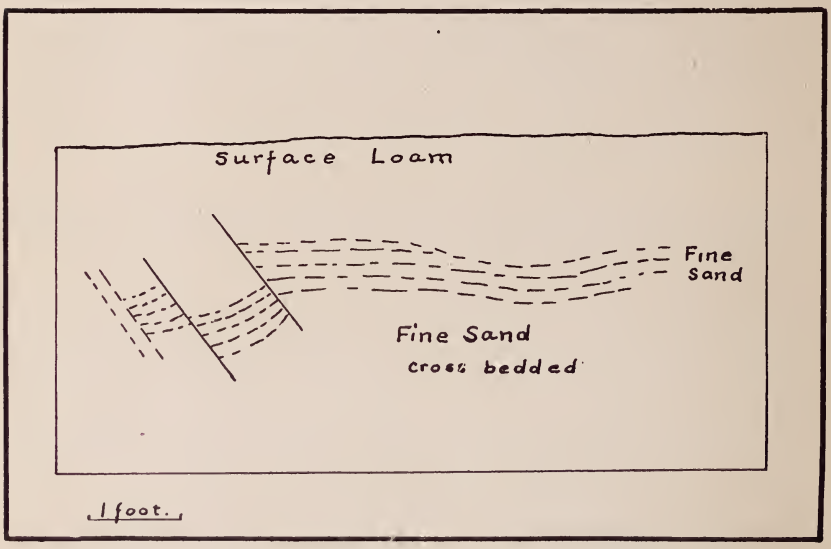


FIG. 11. Cross section showing faults in stratified drift.

tremely unlikely that all was subsequently removed by erosion. But as no till has yet been found overlying the clay, its absence must mean that the glacier never overrode the deposit in question. Besides, some of the planes of deformation both in the clay and elsewhere seem to bear little relation to possible direction of glacier movement and hence require a different explanation.

(b) Floating ice, either as massive bergs or wide stretches of floe ice, when it runs aground, might easily scrape or buckle up the top layers of a deposit, as has already been suggested. Such

a method would apply particularly well to those local disturbances whose plane of deformation bears no relation to the direction of glacier movement: the direction of movement of floating ice may be quite variable depending as it does upon shifting currents and winds. This would be true of any place where water had been ponded. In the Quinnipiac basin, for instance, large masses of ice could exist, might gain sufficient headway, under force of strong wind, to deform and buckle up the clay deposits on running aground.

(c) There is a third way that ice may disturb surface deposits, namely, by ice-thrust. This will be possible only where the overlying water receives a complete cover of ice. This ice cover under changes of temperature may expand and exert a powerful pressure along the shore. Instances of this kind are known where such ice shove has pushed, bent, and piled up the shore deposits several feet in depth, even uprooting large trees.

(d) Gravity.— Many substances tend to move slowly down slopes by the pull of gravity; this is often spoken of as "creep." Under special conditions large masses may move considerable distances and are known as "landslides." Any such movements must necessarily disturb that particular group of strata and also others with which they come in contact. No real landslides have occurred in this region but the principle involved has worked to a lesser degree. This sort of movement, resulting in bending and crumpling of the layers is confined particularly to the clay deposit of the Quinnipiac. Favorable conditions for this deformation exist where erosion has cut a more or less steep bank in the deposit. Some one of the clay layers especially wet and slippery acts as a gliding plane and the mass above moves along it. The size of the mass involved, the rate of movement, and the time determine the amount of crumpling or folding.

In summary it may be said that it is not likely that all of the disturbances seen in the area were produced by any one of the above methods; indeed the discrepancy between planes of deformation and glacier movement exclude that agent in several cases; the position of disturbed strata at a level which well may have been near a shore line suggests strongly the third method — ice-thrust: and disturbed strata occurring in regions known to

have been deeply ponded, etc., point to berg action, etc. Each case must be decided on its merits and but one thing need be emphasized, namely, none of the disturbances actually demand an overriding by the ice.

TEXTURE.

The fragments in stratified drift are uniformly rounded; they are true "water-worn" materials. Pebbles in the gravels are well rounded, some of them being almost spherical. This is true of the small pieces down to a certain size; but the finest sand grains are not rounded; and the very large cobbles and bowlders have only their sharp edges smoothed off. The degree of rounding depends on the resistance of the material, the distance traveled, and to some extent on the original shape of the fragment. It has been found that any grain having a diameter of 0.1 millimeter or less can be reduced no smaller in transportation by water. Sorby has shown that such small fragments are surrounded by a protective cushion of water which is not ruptured by their impact against other fragments, hence their bulk is not reduced nor their shape modified.

The sizes of the fragments may be described by the loosely used terms: sand, gravel, clay. These terms are so indefinitely applied that the writer has undertaken to give them exact definition by using a set of screens as follows:

1m=Screen having 1 mesh to the inch
2m=Screen having 2 meshes to the inch
4m, 8m, 16m, similarly.

The smallest, 16m, is the size of mesh in the ordinary window screen.

The portions separated by the use of these screens were compared by weight and in this way a series of quantitative, mechanical analyses were made. Above 1m, individual pieces are described according to the length of their diameters in inches. Any part of the stratified drift is of course a mixture of variously sized fragments, but the mixing is according to a definite (within limits) percentage of each of the sizes. Five different types were recognized: sand, gravel, coarse gravel, cobbles, bowlders; a sixth

type, clay, requires special treatment. There are all gradations between the types, but the intervals chosen between each are wide enough to be distinctive.

Sand includes ordinary sands as the term is popularly applied, such as are used for masonry work; analyses from four samples of clean building sand follow:

	1.	2.	3.	4.	Average.
2m-4m	0.9%	2.3%	0.6%	0.8%	1.1%
4m-8m	0.7	2.7	1.6	1.6	1.6
8m-16m	1.1	10.0	5.5	6.3	5.7
Less than 16m	97.3	85.0	92.0	91.3	91.5

The great bulk, at least 85 per cent., is less than 16m. Occasionally a pebble may be found which is greater than 2m, but none greater than 1m.

Gravel contains a certain amount of sand and also larger fragments, as is shown by the following analyses:

	1.	2.	Average.
Greater than 1m	0.0%	0.0%	0.5%
1m-2m	12.0	8.0	10.0
2m-4m	16.0	16.0	16.0
4m-8m	12.0	13.0	12.5
Less than 8m	60.0	63.0	61.5

It is seen that about 25 per cent. of gravel grains is greater than 4m. Though not shown in the analyses, in some exposures there are occasional pebbles larger than 1m, the maximum size being 3 inches.

Coarse gravel has increased amount of the large-sized materials. Analyses of material from five typical localities are as follows:

	1.	2.	3.	4.	5.	Average
Greater than 1m	46.0%	36.0%	27.0%	21.3%	39.1%	33.9%
1m-2m	21.0	21.0	20.0	19.2	19.1	20.0
2m-4m	14.0	12.0	13.0	12.2	10.1	12.2
4m-8m	7.0	5.0	11.0	9.0	6.1	7.6
Less than 8m	12.0	26.0	29.0	38.3	25.6	26.2

The pebbles greater than 1m have a maximum diameter of 7 inches, most of them being 2 to 4 inches. At least 50 per cent. is greater

than 4m and 20 per cent. greater than 1m. The intermediate sizes, particularly less than 1m and greater than 2m, are quite constant, the variation appearing in the extremes of the series; this hardly seems to be a coincidence.

Cobbles may be described as a type of stratified drift having pebbles 7 to 12 inches in diameter set in a matrix of coarse gravel or, less commonly, of gravel or sand.

Bowlders make up the type of drift having individual fragments which are greater than 12 inches in diameter; the matrix usually has the texture of cobbles or coarse gravel (see Pl. VI, *B*).

Places are known where 95 per cent. of an exposure is sand but where there is an occasional cobble or bowlder, probably brought in by floating ice.

The types indicated by the analyses may be tabulated as follows:

Types	Greater than 1m	1m-2m	2m-4m	4m-8m	8m-16m	Less than 16m
Coarse	20-50%	25-35%		5-15%	No more than 40%	
Gravel	Max. 7in.	20+%				
Gravel	1+%	20-30%		10-20%	No less than 40%	
	Max. 3in.		15-%		15-30%	
Sand	0%	1+%	1-5%		No less than 90% 1—10% Commonly 85-95%	

The types described are offered as standards until the gathering of more extensive data demands a revision.

As any one exposure may not be a pure type, each exposure of the drift should be classified according to its predominant type. On the other hand there may be so much variety in a single exposure that each bed or group of beds should be described separately. Both methods have been used by the writer.

The purpose of analysing the deposits will be appreciated when it is realized that the size of a fragment is a measure of the strength of the stream that carries it. The position of glacial streams can thus be determined by the position and texture of the deposits they left behind.

A, Upper gravels resting unconformably upon lower sands.

B, Bowlders resting on sandstone at outlet of Lake Dawson.

Clay, the sixth type of stratified drift, consists of very fine grains all of which will pass easily through the 16m screen. Though in general different, because of its stickiness, plasticity, etc., from the other types, clay is also a mixture of variously sized particles.

Pure clay has already been definitely described as to the size of its component grains,[1] which are extremely small (0.005 to 0.0 millimeter); but ordinary clay, such as is used in the arts, contains coarser though not large grains. A common brick clay of good quality has, besides its pure clay content, a large proportion of grains the size of silt (0.05 to 0.005 millimeter), a certain amount of finer sand (0.25 to 0.05 millimeter), and may also have a small proportion of larger sand grains (1 to 0.25 millimeters). In the sand and gravel types above described is always a very small per cent. of true clay, and here and there are small lenses and pockets of fine sand containing an appreciable amount of clay, all of which could well be included in the type sand, if there were not large deposits of commercially valuable clay which require special consideration (see p. 52).

Exclusive of clay deposits, stratified drift has a loose, open texture, and cementing substances are commonly lacking. On account of this quality, excavation is easy, but the material readily caves in. Any considerable cut in stratified drift can hardly get well under way without several thousand dollars worth of timber and planks.

COMPOSITION.

The variety of rock fragments present in stratified drift depends on its texture. In the coarser grades — gravel, coarse gravel, and bowlders — there are just as many different kinds of rocks as in till, from which they have been derived. The coarse materials have not been transported far enough to lose their character. This is true to a lesser degree of the coarse sands. The sands, particularly the finer grades, show much less variety and may have scarcely any rock fragments. They are composed chiefly of mineral fragments — quartz, feldspar, varying small

[1] Soil Survey Field Book: U. S. Dept. Agr., Bur. Soils, pp. 17 and 18, 1906.

amounts of magnetite, garnet, muscovite flakes, and rarely other minerals; the rock fragments when present are commonly fine-grained sandstone. The abrasion and disintegration caused by transportation may have reduced the rock to mineral fragments, but as the materials were not carried great distances it is more reasonable to assume that most of the change from rock to mineral took place before transportation by water.

COLOR.

Like till stratified drift has two colors — yellow-brown and reddish brown. The former is the more common, particularly at the surface; but red-brown is not uncommon, particularly where excavation has exposed the lower strata. In some places the fine sands are bright red, in others they are pale red. If yellow and red are present in section the yellow is always above. On appearing at the surface each color is modified by admixture of organic matter which darkens the tone.

In some places a color, pale yellow to nearly white, has resulted from bleaching caused by solutions from overlying organic matter. The sand layer immediately beneath the peat deposit in the Quinnipiac Valley is an example.

The red color is due in part to small grains of red shale or sandstone, in part to pink feldspar grains and garnets, and in part to quartz grains coated with a thin film of hematite. The yellow color is due partly to the lack of red fragments of minerals or rocks, more commonly to the change of the film of hematite on quartz grains to limonite by weathering.

THICKNESS.

In some places, usually on the margins of the deposits, stratified drift is only 2 to 3 feet thick, and many wells obtain water in stratified drift at depths of 12 to 40 feet. In one place a thickness of 276 feet is known, in a number of places a thickness of over 100 feet, and in still more a thickness of 50 to 100 feet. At one place a boring 76 feet deep struck no rock, and at another a 90-foot well passed through sand and gravel without meeting a ledge.

UPPER GRAVELS.

Differences in color, texture, and structure make it advisable to classify stratified drift as upper gravels, lower sands, and clay.

Upper gravels, so named because of their position and texture, occupy the upper portion of stratified drift and have a thickness of 8 to 25 feet. Sands are found in it, but gravel, coarse gravel, cobbles, and bowlders predominate. The upper foot or so is in many places sandy, even where the bulk of the formation is coarse gravel. Elsewhere the coarse grades persist to the top. The only considerable variation in texture noted is the clay deposit in Hamden, southwest of Cherry Hill, which grades out into coarse material.

The structure shows considerable variety. Cross-bedding is common, and the flow and plunge structure (see Pl. V, *A*) is found in several places. Layers are short and lenslike and change rapidly in character vertically and horizontally (see Pl. VI, *A*). But where made of coarse gravel or bowlders, the layers may be thick and massive for perhaps 100 yards in length (see Pl. VI, *B*). The color of the upper gravels is yellow-brown. They lie upon the eroded edges of the lower sands.

LOWER SANDS.

The lower sands formation lies directly beneath the upper gravels. It consists of sands of various grades — coarse sands, ordinary building sand, fine sand which is often spoken of as quicksand, and some claylike material but no clay deposits either of commercial quality or extent. Locally gravel layers may be found in the lower portions.

The lower sands are characteristically even-bedded, cross-bedding is lacking or on a small scale; the layers are of greater extent; not prominently lenslike, and vary slightly. The color is red-brown ranging from a distinctly bright color to the more common quieter tones.

The division between the upper gravels and lower sands is a plane of unconformity wherever observed. In the New Haven plain it was seen along the whole "cut" where the Shore Line enters the city, also in more than 20 other scattered localities.

At five places each in the Farm and Mill River valleys and at ten different places in the Quinnipiac Valley the same condition exists. The exposures are sufficient in number and widely enough separated to indicate that the unconformity is a regional feature. The upper gravels rest directly upon the eroded surface of the lower sands. There is no intervening soil layer. An undetermined amount of the lower formation was removed by the waters that brought in the upper (see Pl. VI, *A*).

Since they possess such different qualities, it is obvious that the two deposits must have accumulated under unlike conditions. The character of the upper gravels points to vigorous, shifting currents with abundant supply of materials, and that of the lower sands to moderate or slight currents with moderate but steady supply of material. In quantity the lower sands greatly exceed the upper gravels. The difference in color also leads to the conclusion that the materials were gathered under different conditions. The yellow-brown of the upper formation could not have been produced by weathering after the deposit was formed, for the color is uniform from top to bottom and stops abruptly at the line of contact below.

Since stratified drift has been derived from till it follows that directly after the deposition of the till and the withdrawal of the ice, erosion working upon the till gathered material which was carried away and accumulated as the lower sands. These are red because the till from which they were derived was red due to the great quantity of local rock débris present. Wherever the lower sands are near the crystallines, that is, nearly off the sandstone area, the red color is not so pronounced — as should be expected under this theory. The vigor of this erosion and accumulation diminished or perhaps stopped and a certain amount of time elapsed; the length of this time interval can not be definitely stated, but it was long enough so that during it the till weathered probably to considerable depth; the weathering of course changed the color of the till from red-brown to yellow-brown, similarly as we find it today.

Then a new cycle of erosion and transportation ensued. The yellow-brown till was removed, carried, deposited, and became the upper gravel. The initiation of this cycle and the increased

strength of the currents during this second period might have been due either to climatic change inducing a period of heavy rains, or more likely to increased rate of melting of the near-by glacier ice. This second period was not as long as the first, for the thickness of the formation is very much less. That we do not find a second red-brown deposit in the upper part of the upper gravels shows that erosion had not continued long enough to cut through the weathered part of the till and attack again the unchanged redder portion. Contemporaneous cutting of the upper part of the lower sands would produce an eroded surface for the upper gravels to rest upon.

DIRECTION OF CURRENTS.

The directions which the main currents took in transporting stratified drift can be determined by noting the texture of the deposits. A line of coarse gravel flanked on either hand by lines of gravel or sand means a stream with a central swifter portion, and a change in texture from place to place indicates a corresponding change in the strength of the currents. Many pits, cellar holes, cuts, and excavations for water or sewer pipes have been examined with the view of gathering sufficient data to reconstruct the lines of drainage (see Pl. I and fig. 15). Attention has been necessarily confined to the upper gravels.

In Plate I the varying textures of drift are plotted, determining the general course of the currents that brought in and deposited the upper part of the stratified drift (upper gravels). In figure 15, a portion of the area is marked with the current directions. The most striking feature in this connection is the close relation between the glacial currents and the present drainage. The waters collected from many points in the uplands and concentrated along the four main valleys in much the same way as today, but the glacial streams were larger and more active. All the types of stratified drift (p. 40) are represented, even to bowlders. Coarse gravel is very common. The ancient West, Mill, and Farm rivers had the swiftest currents. Mill River, for example, has coarse material thoughout its extent, the deposits being progressively, but slowly, less coarse from north to south,

except where the channel narrows at Mount Carmel and between East and Mill rocks. Probably the bowlders in Fair Haven have been floated in by ice.

The Quinnipiac Valley, in contrast to the other three valleys, has very little coarse material. The texture, with the exception of some coarse gravel near Yalesville and between Montowese and North Haven, is sand or gravel. The first locality is near the head waters of the stream, a natural location for coarse deposits, which give way to finer materials because of the lessening grade of the stream and the widening of the valley. The second locality is near the mouth of Five Mile Brook and represents that stream's contribution to the general valley filling. Augmented by Pine River it built out a wide delta into the Quinnipiac Valley. Not only the coarseness of material at this place but also the dip (north and west) and strike of the planes of cross-bedding show that the tributary was the cause. In other places where the sand of the Quinnipiac coarsens or changes to gravel the change is due to some small tributary, as, for example, near Mount Carmel.

The New Haven plain has been built up by a coalescence of deposits brought by Mill and West rivers plus certain amounts representing the drainage from the Cherry Hill-Lake Wintergreen region. The conditions were those operating on subaerial deltas, where the streams shift from side to side, cutting and filling, working over the deposit, and spreading it rather evenly. Small erosional channels are occasionally seen in the deposit. This method of work must have been followed by the streams throughout their courses. As a result, long stretches of coarse gravel would be formed, grading upstream into cobbles and downstream into gravels and sands, and varying locally on each side of the main currents throughout the whole valley.

The dip and strike of cross-bedding fit in with direction of currents as plotted by varying texture.

The currents that deposited the lower sands followed much the same paths (Pl. I), with at least one important exception. During the early part of the deposition Mill River could not get through East Rock gorge but took its course to the west of Mill Rock and through the Beaver Swamp region. A reference to the

bedrock map in Plate IX will show that the deeper valley had the route indicated. But as the lower sands were built up and the valley was aggraded until it was on a level with the bottom of the gorge, part of the water was able to pass through the East Rock gorge, which later, during the deposition of the upper gravels, was the most direct route.

FLUVIATILE OR ESTUARINE.

The discussion so far has emphasized the fluviatile origin of stratified drift; deltas have been considered as subaerial rather than submarine. The theory of another type of origin, the estuarine, has been suggested. By this it is assumed that the land was depressed sufficiently for the four valleys to be flooded by marine waters, into which the rivers may have dumped their loads; but distribution and deposition of materials were due primarily to the action of currents and tides within the estuary itself. There are several objections to this theory.

(a) If the land were submerged sufficiently to make estuaries in all the valleys the deposit in each valley ought to build up to approximately a uniform height, the upper limit being determined by the depth of water. But the deposits are not at uniform heights. Along parallel 41° 20′ stratified drift reaches a level of 90 feet in West River valley, 70 feet in Mill River, 50 feet in Quinnipiac River, and 110 feet in Farm River. In the latitude of Lake Dawson, West River deposits have an elevation of 170 feet; Mill River, 100 feet; Quinnipiac River, 70 feet; Farm River, 170 feet; and on an east and west line about one mile north of New Haven, deposits reach a level of 100 feet in Mill River, 80 feet in Quinnipiac River, and 200 feet in the Farm River. These figures show a great difference in the heights above sea level of the deposits in the various valleys. Though it is possible that movements took place after the deposition of stratified drift, causing a difference in the heights of the valleys, it is not probable that so much action could take place in so restricted an area without leaving other traces; a movement affecting a valley as a unit very likely would affect parts of all the valleys. It might be urged that the filling of the estuary is determined by the amount of sedi-

ment brought in and the depth of the water. This is true and might possibly account for the great difference of level, and if this were the only objection it might be ignored. If the currents in the estuary were as vigorous as is implied by the size of the material, they could easily have carried away and deposited all the load of stratified drift as fast as it was supplied by the rivers and such differences of elevation would not be necessary.

(b) The second objection is based on the texture of stratified drift. Coarse gravel and cobbles are found spread along the valleys for several miles, in the case of the Mill River valley throughout its extent, a distance of fourteen miles. It is not conceivable that the waters of any estuary could transport such coarse material so far. The water of an estuary is rather quiet except in narrow estuaries having high tidal action — as in the Bay of Fundy — in which cases the greatest activity of the currents is at the outlet and results in much scour and erosion. In the New Haven region there were (if we assume an estuarine origin) four narrow estuaries. But their outlets are places of deposition rather than erosion. There is no reason why the tidal action should have been more vigorous in the Mill than in the Farm estuary, nor should the tidal currents have been the cause of the quantity of coarse material in the New Haven plain and the lack of it in the East Haven plain. Currents caused by tidal action could not have produced the variety of texture found in regions of similar topographical position, and currents initiated by large streams entering at their heads could not have been maintained for any long distances. The only possible way that estuaries could have coarse materials throughout their extent is in the case of rather narrow estuaries with a great number of marginal tributaries flowing into them, each tributary being active and carrying a good load. If these tributaries were all of equal strength, all carrying the same loads or nearly so, and all were close enough together so that their deltas coalesced and made a continuous deposit, then the floor of an estuary would be built up by a deposit that simulates the deposit found in the region under discussion. But such a complete combination of conditions would be entirely fortuitous and extremely unlikely. That such conditions did not operate in Connecticut is seen when, for ex-

ample, the deposit on each side of East Rock is considered. As the drainage from the cliff on the west side of the rock would have been practically nil, assuming a marginal drainage filling, practically all the Mill River deposit must have come from the east slope of Prospect Hill. The east slope of East Rock would be an equivalent to this and though the deposits in the Quinnipiac Valley are sand, in Mill River valley they are coarse gravel and cobbles.

(c) Absence of any shore phenomena is another objection to the estuarine theory. A body of water should make a record of itself along its point of contact with the land. Beaches and other evidences of wave work are, however, not found on the New Haven plain. They may have been obliterated by subsequent erosion, but it is unlikely that all traces would have been removed.

(d) A final objection is the lack of fossils in stratified drift. Only one fossil has ever been known — two bones of a land animal, reindeer, found in the clays of the Quinnipiac.[1] If marine waters were present when the deposits were laid down some record of the marine life would have been made, and even if not abundant it would have come to light somewhere in the numerous excavations for cellars, wells, sewers, water mains, trolley cuts, etc. The writer has studied over 150 different exposures and has information concerning as many more, but no fossils have been found. If they were ever there surely diagenetic changes could not so have obliterated all traces of them! The coldness of the glacier waters did not necessarily prevent life in them, for arctic waters possess life. Other regions along the coast where the glacier deposits are known to have been marine have fossils.[2]

The assumption that submergence was confined to the lower portions of the valleys with streams in the upper portions is not satisfactory. For instance, assume a submergence to the present 100-foot contour: this would mean a flooding of the whole Quinnipiac Valley, Mill Valley above Mount Carmel, Farm Valley above Totoket, and West Valley nearly to Lake Dawson; and yet

[1] Dana, J. D., On southern New England during the melting of the great glacier: Amer. Jour. Sci., 3d ser., vol. 10, p. 353, 1875.

[2] Stone, G. H., The glacial gravels of Maine and their associated deposits: U. S. Geol. Survey Mon. 34, pp. 41 and 54, 1899.

we find no contrast in texture at these points that would suggest a difference in current velocity, no shore phenomena, and no evidence to show a change of conditions at or near that level. The same objections hold if submergence to other levels is assumed.

CLAY.[1]

Clay is found in commercial quantities at two localities: south (west) of Cherry Hill, Hamden, and in the Quinnipiac Valley. The Hamden clay, which occupies about half a square mile, is inferior in quality to the Quinnipiac clay and has not been worked for fifteen years. The Quinnipiac clay is of much importance because of its excellent quality and large extent; it underlies the whole valley. It is mined in a number of pits between New Haven and North Haven and also at Montowese. It appears at the surface in Worton Brook, in the Quinnipiac River at the east end of Mount Carmel, and at another point just below this. It occurs in a deep well at Wallingford. Undoubtedly it is a continuous deposit from the north edge of New Haven up the valley to Wallingford and probably to Yalesville.

Clay does not appear at the surface in many places, except as the cover has been stripped away by man. It is overlain by sand and gravel, which in turn in a large part of the valley is overlain by swamp muck and peat. The depth of this cover ranges from zero to 70 feet.

In the southern part of the valley, at the Davis clay pit, the cover on the west side consists of 5 to 8 feet of sand and gravel with no peat above; on the east side the gravelly sand thins to from 1½ to 2 feet and the peat is correspondingly thicker, 4 to 6 feet; and borings show that the cover thickens rather rapidly southeasterly. At the Stiles pit, about one mile south of North Haven there is little peat, and the gravel and sand increase to from 4 to 12 feet. At the margin of the valley west of this pit the depth of the cover is 70 feet. Between North Haven and Wallingford, peat is absent; clay appears at the surface in three places (see above); and in the city of Wallingford from 30 to 35

[1] The general features of this clay and its economic development have already been treated by G. F. Loughlin in Clays and Clay Industries of Connecticut: Connecticut Geol. and Nat. Hist. Survey Bull. 4, 1905.

feet of sand cover it. In Montowese the sandy cover ranges from 2 to 15 feet.

Evidence shows that the surface of the clay is undulating rather than flat and that it has several channels running through it.

Sand and gravel, which are usually coarsest at the bottom, overlie the clay, meeting is abruptly; the contact is extremely sharp. With the exception of the Hamden deposit, where clay rests upon sand and gravel, clay rests upon rock. The Quinnipiac Valley deposit has been penetrated in four places, and in each of these rock was found immediately below clay. Clay deposits in other parts of the State are reported to rest on till.

Except for peat and swamp the cover is usually sand or sand and gravel, rarely coarse gravel. Some buried tree stumps still upright and portions of tree trunks or logs, the largest one with a diameter of 18 inches, are found in peat. Nowhere in the entire Quinnipiac deposit has till been found overlying clay. The glacier did not, therefore, pass over the deposit, for it is hardly probable that till was deposited and entirely removed later.

The depth of clay is accurately known in only a few places. In the Stiles pit at North Haven a well penetrates 60 feet of clay before striking rock; at Wallingford a well record shows 150 feet of clay; and in two places at the margin of the deposit clay was only 4 feet thick and poor in quality. In workable pits clay has been dug out or explored to a depth of 20 to 40 feet without reaching bottom. With these figures an estimate can be made of the quantity of clay in the valley. If we consider the average depth as 36 feet, which is surely a moderate estimate, the average width as half a mile, and the length as 10 miles, there would be 185,856,000 cubic yards of clay. If the entire amount of clay taken from the Davis pit (which has been operated for 35 years) should be removed each year, there would be enough for more than 1,500 years.

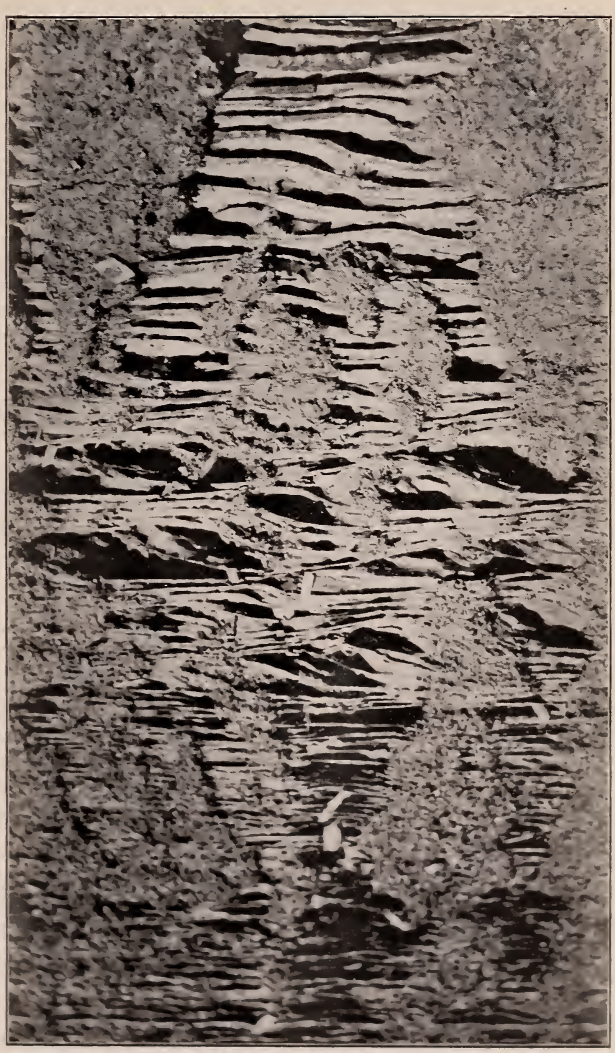
Clay is very uniform throughout the Quinnipiac Valley. It shows with great persistence a regularity of bedding which has given rise to the term "layer clay." Two substances make up the beds, clay proper and silt. These alternate systematically, under average conditions the clay repeating itself fifteen times in each

vertical foot (see Pl. VII). The Hamden clay was not exposed for inspection, but from evidence furnished by those who saw the pits when in operation it lacks the layer arrangement. The clay deposit is uniformly red.

The clay proper is very pure in quality. It is of so fine a texture that no grit can be felt by the teeth and when stirred up in water it will long remain suspended. Because it is extremely unctious and slippery when wet it is locally spoken of as the "grease" layer. These layers are a quarter to half an inch thick.

Silt is also of a fine texture. It has some true clay in it, but it consists essentially of silt and a certain amount of very fine sand. It feels gritty to the teeth and has the appearance and quality of fine quicksand. At the bottom of each layer there is likely to be a thin lamina of small scattered grains of sand. The thickness of silt varies more than clay; ordinarily it is half an inch to 1½ inches thick, in a few instances attaining a thickness of 4½ inches and rarely even several feet. These layers may show a subdivision into very thin laminae, about fifteen to half an inch. The contact of the lower part of the silt and the upper part of the clay layers is uniformly regular, distinct, and abrupt; but the lower part of the clay layers grades into the upper part of the silt.

Concretions are commonly found in the silt layers. They have a great variety of shapes — disklike, globular, finger-like, and many imitative forms — but all are rounded and many are very symmetrical. They are composed of clay and silt plus (50 per cent. more or less) lime carbonate. Unlike many concretions those from the Quinnipiac Valley do not show a nucleus nor concentric banding or onion-like structure, but they do include occasional grains of the mineral, calcite. It seems most reasonable to believe that these concretions were formed subsequent to the accumulation of the silt layers, which contain a certain amount of lime carbonate even where there are no concretions. It is believed that water percolating through the silt layers gathered the scattered lime carbonate; later, under favorable conditions, this was deposited at certain spots in with the silt and clay. The exact mechanism of deposition and its immediate cause, however, are not clearly understood. The clay layers have no concretions, nor do they contain lime carbonate.



Warped layer clay at Shears Clay Pit. Clay layers made prominent by washing away of the silt layers. Warping confined mostly to the central 2 to 3 feet of the series; layers nearly normal are both above and below.

Clay also contains large amounts of the same mineral grains as coarse drift but in a very fine state of division. There is in addition an appreciable quantity of kaolin and other hydrous decomposition products.

The most extensive use of clay is for brick, and it is used to a smaller extent for flower pots and tiling. Because of the regularity of the layers and the proper proportion of silt and clay present, as a whole it requires a minimum of preparation before using[1].

The great regularity and thickness of the deposit suggest uniform conditions existing over a considerable length of time. Since the material is so well stratified and so evenly spread it must be concluded that the clay and silt accumulated in some quiet body of water — a lake, not the sea. The bedrock map (Pl. IX) shows that there was a rock basin with at most only a small outlet to the south.

The regular alternation of silt and clay points to regular changes in supply of material; probably a seasonal change. That is, during one season of the year the streams, due to added water, were more active in getting and carrying rock waste — silt and clay. The silt would very soon settle to the bottom; the clay because of its extremely fine grain would settle slowly, and it might take most of the succeeding season for the waters to be cleared of it. Then when the season of supply came around again a new quantity of silt would be deposited directly and abruptly upon the top of the clay layer, and the process of rather rapidly accumulating silt accompanied by a constantly slow accumulation of clay would begin anew and be followed by a steady but slow accumulation of clay alone.

The cause of the streams' regularity was probably a meteorological or climatic one. The supply streams in the season of accumulation are more active because their volume of water is increased. This increase may be due to rainfall, in which case the regularity must be considered. Under conditions as we know them today our rainy times of the year are spring and fall; under

[1] For a more complete account of clays in general, their qualities and uses and the status of the clay industry in Connecticut the reader is referred to G. P. Loughlin's Clays and Clay Industries of Connecticut: Connecticut Geol. and Nat. Hist. Survey Bull. 4, 1905.

this count of two, each two clay layers indicate a year in time. There are on the average 15 clay layers to the vertical foot; if the average depth of the clay deposit is considered to be 50 feet there would be 750 clay layers, which on the above assumption of two a year makes 375 years for the accumulation. If a rainy and dry season are considered as operating at that time we would need to conclude that each clay layer represented a year, making the total time 750 years, and if the average depth taken is 75 feet the time would be proportionately longer. On the other hand, if we try to shorten the time by assuming other rainy periods than spring and fall we are confronted by the regularity of the deposit: our monthly or weekly rains hardly come with the regularity indicated by the deposit. A period shorter than a week could not be assumed, for the clay would not have time to settle.

The regularity need not, however, be one of time but of supply. This will be better understood by considering first the action of different-sized particles in water. The rate of subsidence of any particle through a column of quiet water depends on its mass, which in turn is dependent upon its diameter. Specific gravity need not be a disturbing factor, since ordinary sediments are approximately the same in this respect, namely, about 2.6.

Figures given by Hall[1] show that particles fall at the following rates:

(x) Diameter 0.04-0.01 mm. Fall 10 cm. in 100 sec.=12 ± ft. in 1 hr.=288 ft. a day.

(y) Diameter 0.01-0.002 mm. Fall 7.5 cm. in 12½ min.=15 in. in 1 hr.=30 ft. a day.

(z) Diameter 0.002-0 mm. Fall 8.5 cm. in 24 hrs.=3.4 in. in 24 hrs.

Silt particles as defined by the Bureau of Soils[2] have diameters 0.05 to 0.005 millimeters. This is intermediate between (x) and (y), and an estimate of 100 feet a day would be conservative, and the coarse part of the silt with the fine sand grains would fall that distance in a few hours. Clay particles which have diameters 0.005 to 0 millimeters would be intermediate between (y) and (z), so the coarser clay particles could easily fall a distance of 5 feet in a day, intermediate particles less than a foot a day, and the finest would remain in suspension indefinitely.

[1] Hall, A. D., The Soil, pp. 52 and 53, 1907.

[2] Soil Survey Field Book: U. S. Dept. Agr., pp. 17, 18, 1906.

If the Quinnipiac lake, therefore, had a depth of 75 feet, the bulk of the silt layer, composed of silt proper and some very fine sand, would fall through 75 feet of water in a few hours and all of it in less than a day; the bulk of the clay layer, composed of clay proper and fine silt, would need from 5 to 15 days to settle through a distance of 75 feet, and the remainder would require from one month to five months.

Assume that the Quinnipiac lake received a supply of mixed fine sand, silt, and clay. At the end of 24 hours the silt layer as we know it, containing some fine silt and clay would be deposited, the clay increasing as the top of the silt layer was approached and grading into the clay layer proper in the 5 to 15 days needed for its accumulation on top of the silt layer. After that, clay would continue to fall very slowly and in extremely small quantities. If a second similar supply was received 15 days later the process would be repeated with the second silt layer resting abruptly upon the top of the first clay layer.

Providing the supply was the same every time, the appearance of the layers would be alike whether the interval between the supplies was 20 days or 6 months. The uniform thickness of the many layers shows that the supply was the same, as only locally do they vary. The depth of the water would make some difference in these calculations. The bulk of the clay deposit is more than 40 feet thick, in one instance 150 feet, and a certain amount of water was present above the topmost layer. The depth of the water would be lessened by the constant filling of the lake basin. However, its depth is probably not a critical factor, for a vertical range of 20 feet in the deposit shows no perceptible variation in the thickness of the layers. Consequently, the conclusion drawn is that each layer had sufficient time to accumulate, and that though the time interval between supplies might have been extremely variable, the amount of the supply was regular and uniform.

That each rainfall in turn was of such uniform intensity and character as to cause the erosion and transport of the same amount of material in every case seems unlikely, so another explanation is given:

A glacier is melting at some point all the time, less near its source and more at it lowest extremity. Its melting depends somewhat on pressure but chiefly on the temperature of the surrounding air and the action of the direct rays of the sun. Hence the greatest melting will occur in warm seasons and during the daytime. The amount of water resulting is quite uniform. It has been noted that streams flowing from banks of perpetual snow have a minimum volume in the early morning, that the volume increases as the day advances and reaches a maximum in the afternoon. Day after day as long as the climatic and weather conditions are uniform, the waters rise to the same height and fill the valley to the same level. A similar seasonal regularity is based on the daily supplies. These come from countless different parts of the glacier; merge into one another, one day's melting overlapping the next farther along the line; and eventually the major drainage channels receive a steady supply of water throughout the summer season. The position of the ice front may change and so modify the situation, but its change is slow and due also to climatic conditions. The presence of occasional cobbles and bowlders in clay deposits points to floating ice as a carrier. This does not necessarily imply glacier ice fragments, river ice would serve as well.

Hence, by the seasonal melting of the glacier ice a regular supply of water was liberated; this in turn carried a uniform amount of silt and clay each season. The clay deposit, therefore, must have accumulated while the ice front was rather stationary some distance to the north of the Quinnipiac basin. Its location is not known positively. It could not have been very near, for the waters had already lost the coarser parts of their load; if too near, the diurnal variations in supply would have given a more mixed character to the deposit, while being far enough away the steady seasonal supply, already described, would bring more uniform material. Probably the ice front was not far north of Yalesville.

The time involved in the formation of a silt layer and a clay layer, according to the method above described, would be a year. With the average of 15 layers to the foot and with a depth of 50 feet, 750 years would be required to build up the deposit, which

would be increased to 1,125 years if the average depth is considered 75 feet. The depth of 150 feet noted in one place would indicate 2,250 years. But it is not known absolutely that the same average — 15 layers to the foot — holds true for the entire depth, and in fact some local variation lessening that figure is known. Nor is it certain how much, if any, of the deposit has been removed since its completion. Owing to the incomplete record no definite figure for the time involved can be given, but it is safe to say that the deposit required at least 500 years and no more than 2,500 years for its accumulation.

The clay layers have been disturbed subsequent to their deposition as evidenced by broad bendings and by a warping apart (see Pl. VII). Others are crumpled or broken and faulted (see fig. 12), the faults being of the reverse or thrust variety; the large thrust fault shown in the stratified series, Plate VI, *A*, involves clay in its lower portion. Another type is as follows: a group of layers (*x*, fig. 13), 1 foot to 2 feet wide and about 5 feet below the top of the clay, is intricately crumpled, but both above and below the layers are but slightly disturbed. The assumption in

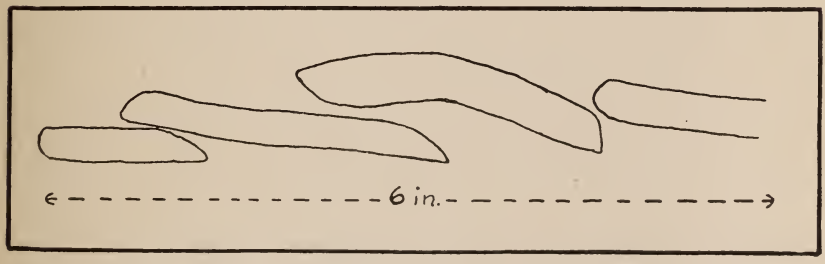


FIG. 12. Cross section showing deformation of clay layers.

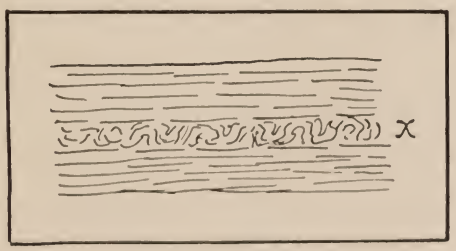


FIG. 13. Cross section showing deformation of clay layers.

this case is that the upper beds were moved bodily, and the group of layers, *x*, acted as a gliding plane. It is believed that the deformation of clay and the other parts of stratified drift has resulted from a common cause or causes.

TERRACES.

Terraces form along river valleys whenever the river after building a flood plain changes its habits and becomes an eroding stream. Those parts of the original flood plain that remain on either side of the valley are the terraces. Terraces may also develop along the margin of a body of standing water by the action of the waves. They may be formed in any type of material: solid rock, silt, sand, or gravel, and they are continually subjected to weathering and erosion which may remove or obliterate them.

In the New Haven region terraces are most common in stratified drift. All the large valleys and many tributary valleys have them to some extent, but only along parts of their course are they well developed, and they may be entirely lacking. Usually there is only one terrace lying 15 to 25 feet above the present flood plain of the streams. In a number of places there are two terraces, the upper one standing 10 to 15 feet above the lower, and the lower one 5 to 15 feet above the flood plain.

Stratified drift is an accumulation that has filled in the valleys (see *A*, fig. 14). If the process of removal starts near the center a terrace is formed on each side of the valley as a *B*, but if it starts from the margins (*m* or *o*), particularly where the drift rests on rock, the underlying ledge acts as a resistant floor from which the waters can easily sweep the looser stratified drift. The process initiated, perhaps, by drainage down the slope into the valley would result in a terrace on one side of the valley only (*C*, fig. 14). The same result might occur where stratified drift rested on till rather than on rock, for the two materials are unlike in texture and the effect of water falling on them would be different. As stratified drift is porous, water will soak into it rather than move along its surface, but the compact till tends to retain the water on its surface. Supposing the terracing process started at the margin *m*, water would soak into stratified drift at that

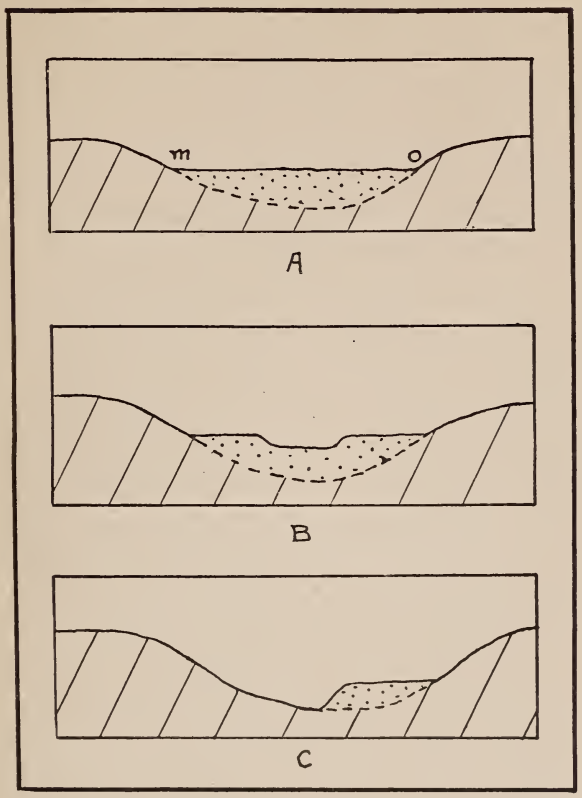


FIG. 14. Cross sections showing formation of terraces in valley fillings of stratified drift.

point, would meet the more impervious till, and move along its upper surface carrying the less coherent stratified drift along; continuation of this process would strip back the stratified drift until the conditions seen at *C* resulted, or all the stratified drift may be removed, leaving no terrace.

Less commonly terraces are found in rock. They are found at a few points along the main valleys and a little more commonly in the tributary streams flowing from the uplands. In some places deposits of drift obscure them. The presence of till over the rock terrace means that the cutting by the streams took place before the deposition of till or stratified drift. At one place a pot hole was found on the terrace.

The energy of a stream is expended both in erosion and transportation, and whether a stream will cut or deposit depends on the balance between velocity and load. A stream will change to the cutting habit when it has either less load to carry or greater volume of water for the same load, or greater slope with the same volume and load than formerly. In the New Haven region the load may have lessened as the glacier receded. The melting ice may have furnished the same amount of water when the glacier was much farther to the north, but the load would most likely be dropped nearer to the ice front. There may have been, therefore, a progressive filling and terracing as the glacier retreated. The increased activity of streams indicated by terracing may also have resulted from an increased volume of water due to a faster melting of the glacier or to increased rainfall in response to a climatic change. Terracing in the glaciated region of the United States has usually been ascribed to a progressive change of level in the land as the glacier withdrew. There are three objections to this theory of elevation as a cause of cutting:

(a) The cutting is uniformly deep throughout the valleys. If elevation alone were the cause, the amount of cutting along the valley from source to mouth would depend upon the position of the original stream with reference to base-level. If at base-level then with a uniform elevation of x feet a trench x feet deep would result. If the elevation were differential — nearer the source — the trench would deepen towards the headquarters of the stream. As a matter of fact, the terraces do not become higher as the upper parts of the stream are approached, nor were the streams at or near base-level when terracing began.

(b) The terraces are so little cut by erosion channels that a rather recent cutting is implied. But the assumed elevation occurred immediately after the withdrawal of the ice, which would mean a longer time since elevation than erosion suggests.

(c) A simpler explanation is possible. It is believed that cutting has resulted upon increased volume of streams due to climatic changes.

The same waters that formed the terraces in the stratified drift did not produce those formed in the rock, for they are overlain by till. These latter were formed at an earlier period. They

may be entirely preglacial. But more likely they were formed as the glacier advanced, the cutting being initiated by the added waters from the oncoming glacier.

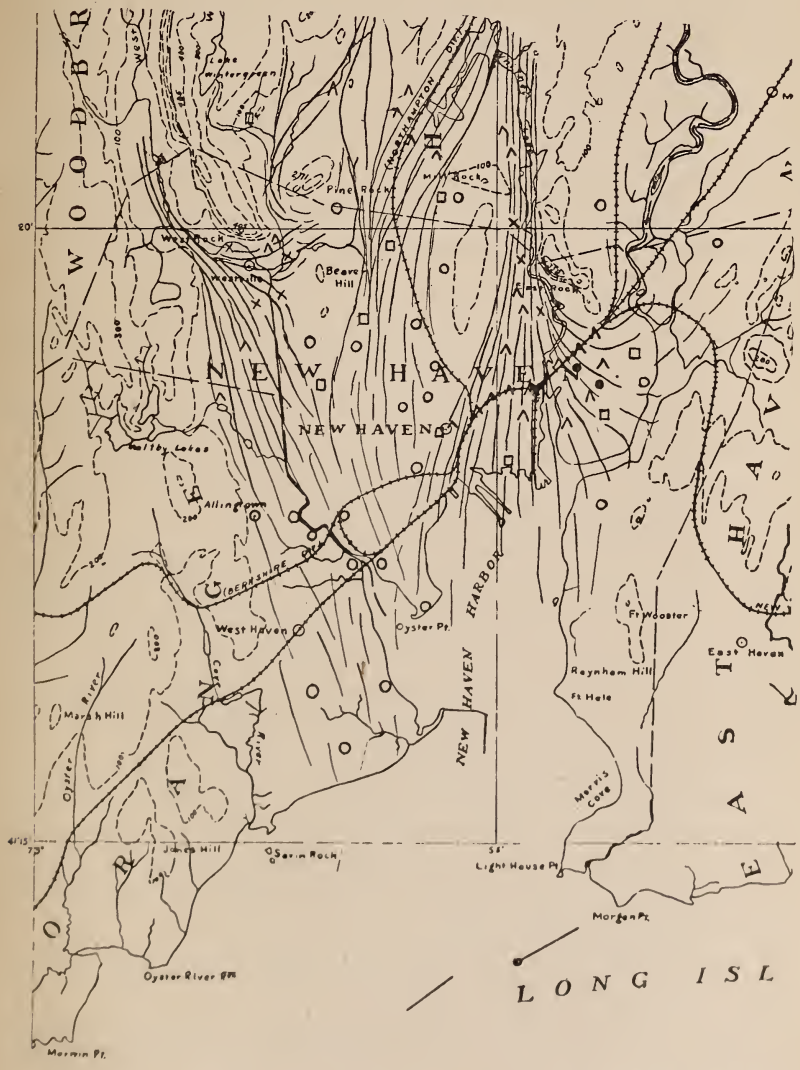


FIG. 15. Map showing location of currents which deposited stratified drift. The symbols are those used on Plate I.

Those seen around the New Haven plain have been considered by some as wave-cut, implying that the region was submerged and inundated by the sea. But they are obviously connected with the terraces seen in other parts of southern Connecticut, which stand at various levels. Subsidence that would have brought all the terraces to sea level would necessarily have been impossibly intricate and differential.

The terraces show very little dissection. This may mean that because of the very porous nature of most of the stratified drift waters soak in rather than erode; but it more likely means that the land was terraced rather late in the glacial period, and that erosion has not yet had sufficient time to accomplish much dissection.

SUMMARY OF CHARACTERISTICS OF TILL AND STRATIFIED DRIFT.

For the benefit of those who wish to distinguish till from stratified drift the following outline is offered for guidance:

Structure. Till is a heterogeneous mixture without bedding planes. Stratified drift lies in beds or layers.

Texture. Till is compact; usually has a clayey matrix; in many places contains large bowlders; has angular or subangular fragments that may be striated; has wide variation in size of fragments in a single exposure. Stratified drift is loose-textured; is usually sandy; large bowlders unusual; has rounded and "water-worn" fragments that never show striations; in any one exposure shows a limiting size to the fragments.

Topography. Till shows irregular or undulating topography, extensive flats are extremely unusual; is abundant on slopes and uplands; is never terraced. Stratified drift is commonly flat or has little relief; is typically along drainage lines, particularly the lowlands; is much terraced.

Depth. Till is usually 2 to 15 feet thick. Stratified drift is usually 20 to 75 feet thick.

Soils. Till is usually stony, strong, late. Stratified drift is usually sandy, light, early.

Swamps. They are common on till. They are much less common on stratified drift.

A, Glacial striations at Blakeslee's Quarry, Fair Haven Heights

B, Young peach orchard on stony till soil.

Since till and stratified drift vary in color, texture, composition, and thickness a single feature may be insufficient to differentiate them.

BEDROCK.

In some places bedrock appears at the surface, in others it is covered by more than 200 feet of drift. On the whole, solid rock is rather near the surface, as may be seen in Plate IX. In fully 75 per cent. of the New Haven region, excepting the broad valleys and the New Haven plain, rock lies within 20 feet of the surface. The rock surface is not jagged or intricately irregular, but presents broad, smooth curves in profile. In many places this undulating surface is marked by parallel grooves or scratches (see Pl. VIII, *A*). The significance of loose débris resting abruptly on solid rock will be best appreciated by considering the relations existing between rocks, weathering, and soils.

A significant feature of the bedrock in southern Connecticut is its freshness. Glacial drift lies directly upon solid unweathered rock. In unglaciated regions bedrock is rotted and decomposed at the top, forming a soil the depth of which depends upon the kind of rock, the climate, slope, and the length of time involved. Such soil, which must have formed the upper surface of rock in the New Haven region before the coming of the glacier, was stripped from the ledges by the moving ice sheet. In its place was deposited drift.

The ice not only scraped off the loose soil layer but also cut into the unweathered ledge to an appreciable extent. The rock fragments held in the lower part of the glacier were the graving tools which enabled it to dig into the rock, to gouge out depressions, and to make striations and grooves, which mark the direction of glacier movement. Most of these marks show that the movement was southwestward; another and rarer set shows a general southward movement (see Pl. I).

Though the two general trends of the striae may mean two advances of the glacier, it is probable that the variation is due to local modification of the general movement. It is known that large valleys whose general bearing does not depart widely from

the trend of a continental glacier can control the movement of the ice within its walls. Even minor irregularities of the rocky floor may exert a similar control, for example, at one place where the general direction of ice movement was S. 5° W. a small channel not more than 75 yards wide at the top and about 30 feet deep has modified the movement by 30°, the striae within the channel pointing S. 35° W., and on the top S. 5° W. One groove on the upper edge of this channel showed a transition without superposition of one set of striae on another.

PREGLACIAL TOPOGRAPHY.

Since the glacier has both taken away material from the rock and brought other material, it is obvious that the topography of the present day must be different from that in preglacial time, and it is possible to reconstruct this preglacial landscape. In order to do this we must in imagination remove all the loose glacial débris, leaving the solid rock bare, then add 10 to 50 feet of loose rock and soil to the ledge. Although many of the larger features would be much the same yet there would be changes, and some of them radical. The outline of the hills would be sharper and more irregular, the valleys would be narrower and have different slopes, and the flat New Haven plain would not then exist. In preglacial times the land of this region was evidently 200 feet higher than today, for none of the stratified drift is of marine deposition — as has already been shown — and its thickness in the New Haven plain is at least 200 feet.

DRAINAGE.

A glacial region has several characteristic drainage features. Lakes and swamps are common; stream courses have been shifted and otherwise modified.[1]

LAKES.

There are several lakes in the southern part of the Connecticut lowland. They measure the irregularity of deposition of drift, particularly of till. Wherever till is heaped indiscriminately

[1] Rice, W. N., and Gregory, H. E., Manual of the geology of Connecticut: Connecticut Geol. and Nat. Hist. Survey Bull. 6, pp. 247-254, 1906.

many small hollows and basins result, in which the water collects; or drift may block an otherwise open channel or natural drainage line, thus ponding the water. Many kettle holes, especially the deeper ones, hold small lakes. Lakes are not permanent features of the landscape. Their outlets may be cut down and the water drained away, or deposition may fill in and obliterate them.

SWAMPS.

These are more numerous than lakes. Many of them were formerly lakes which have been filled partly with sands and muds brought by streams, partly by the growth of aquatic vegetation, which starts from the margins and gradually builds out, in time covering the whole lake and converting it into a swamp.

Swamps not uncommonly are found on hill slopes where there never were any lakes and where the drainage seems sufficient to keep the slope dry. Swamps of this type owe their existence to the thinness and the close texture of drift. As water from rains or from melting snow sinks into the ground only a foot or so beneath the surface, it meets impervious rock. Most of the water is then forced to move along the rock surface and down the slope, and consequently the top layer of drift is kept soaked and the slope as a whole is swampy.

The same condition may prevail if the hill is composed of till, for much of the matrix of till is very fine and claylike and holds moisture very tenaciously; as a result the water does not soak in readily but is kept near the surface and causes a swamp. In contrast to this, stratified drift takes up water quickly because of its more open texture, and, if in an elevated position, a swamp will be formed only where a dense, claylike layer is not far below the surface.

The small lenses of sand that are found occasionally in masses of till become the trunk channels for water, and if they outcrop on a slope the water content will gradually seep out and produce a swampy spot.

All types of drift regardless of texture will eventually be surcharged with water if in favorable positions. At the margins of the shore, on tidal flats, and along flood plains of streams, swamps

are universally present, because the level of permanent ground water is at or near the surface and the water can not drain away unless the ground water level itself is lowered.

MODIFICATION OF DRAINAGE.

A comparison of the preglacial topography with the present topography shows that the larger streams of the New Haven region have been modified by the filling of their valleys with drift. For instance, in preglacial time Mill River did not pass through Lake Whitney but flowed to the west of Mill Rock, and the Quinnipiac Valley was a lake. Since the main body of drift was deposited minor shiftings of the streams across their valley flats have taken place. A short distance to the north, however, were modifications that had a direct influence on the drainage of this particular area.

POSTGLACIAL FEATURES.

Since the close of the glacial period, weathering, running water, and movements in the earth's crust have produced many changes in topography.

Weathering has been continually at work. As a result many of the bare ledges that once had glacial striae upon their surfaces no longer bear them, but the change has not usually been sufficient to obscure the general rounding and smoothing of the surface produced by the glacier. Some of the shaly sandstones have been affected to such an extent by weathering that soil has started to form upon them, and the loose bowlders and gravels and even the body of drift has become decomposed. The cover of drift has protected the bedrock below.

Minor changes along the stream courses have been caused by the shifting of meandering streams, a more considerable change by rainwash from the slopes to the lower levels. The effect produced is seen best where the flat-lying stratified drift meets the till-clad uplands. Rain falling on a slope will carry loose débris down to its foot and deposit it as an overlap of " wash," a process which has obscured the contact of till and stratified drift in a great many places.

That the land near New Haven has slowly been subsiding since the close of the glacial period is shown by the following evidence: in the swamp in the Quinnipiac Valley are the remains of buried tree stumps as much as 12 inches in diameter; they appear near the lower part of the peat deposit which overlies sand and clay. Though it is true that shallow waters marginal to the coast can be and are gradually converted to salt marsh and even to agricultural fields without any movement of the land, such a depth of water as is indicated by the tree stumps and the thickness of overlying peat would not normally support the growth of trees. The trees must have grown in soil, possibly containing excess moisture, but not in water. A gradual subsidence of the land inundated and submerged the trees and in this water peat was formed.

SEQUENCE OF EVENTS.

The geologic events in the southern part of the central lowland of Connecticut outlined chronologically are as follows:

1. Preglacial conditions. The land was probably 200 feet more or less higher than at present, as shown by depth of the deposit in the New Haven plain, none of which is marine. This general elevation persisted until the withdrawal of the glacier.

2. Approach of glacier. Melting of the approaching glacier increased erosion; valley floors were swept clean and also channeled, resulting in rock terraces in the tributaries.

3. Overriding of land by glacier. Collection of load, removal of loose soil, some cutting into rock; formation of striations, general rounding and smoothing; some deposition where the glacier was overloaded with ground moraine; and lamination of till took place. Preglacial topography was smoothed, bedrock was scraped, the Quinnipiac rock basin was formed.

4. Withdrawal of glacier. General deposition of till. Morainal deposits formed at places where retreat was halted. Dams formed at the southern end of West Rock Ridge and at Mount Carmel. Till worked over by glacial waters; stratified drift collected, carried, and deposited; three periods of deposition.

(a) Deposition of clay. This took place while the ice front was not far north of Cheshire and Yalesville. The Quinnipiac

was a closed basin holding a lake and receiving a regular supply from the melting glacier in addition to drainage from the sides of the basin. The other valleys had too rapid currents to allow much deposition of clay.

(b) Deposition of lower sands. More vigorous streams entered the Quinnipiac Valley depositing sands over the clays. In the other valleys the lower sands were accumulating during and after the formation of the Quinnipiac clays.

(c) Deposition of upper gravels. The change from the period of lower sands to the upper gravels involved an unknown but not excessive amount of time. No interglacial period is implied. A very decided change in the volume and velocity of the currents took place, due to a marked increase in the rate of melting of the glacier as it withdrew toward the Southington position, combined probably with some climatic change.

5. Terracing. An interval of time elapsed between the withdrawal of the ice and the terracing. This period of erosion may have been due to uplift but more likely either to climatic changes or loss of load of the streams.

6. Recent events. Final subsidence with inundation of river valleys in their lower extremities. Formation of peat and salt marsh, also "wash." Conditions of weathering about as at present.

Whether the subsidence was progressive, starting during or after event number 4, or whether it was localized in point of time, is very uncertain.

SOILS.

ORIGIN.

Soil is the loose, rocky débris found on the surface of the earth and usually capable of supporting a growth of vegetation. All soils have been derived in one way and another from solid rock.

The process by which rock is broken down to soil is slow and gradual, involving both chemical and mechanical forces. Just as the walls of many old stone buildings which have stood for 50 or 100 years have started to crumble under the action of the

weather, so has the solid ledge of the earth slowly fallen to pieces when exposed to sun, moisture, rain, gases of the air, frost, and wind. Exposed portions of rock are reduced to fragments and the fragments in turn to smaller and smaller pieces.

In many places, as in some quarry or railroad cut, the solid rock can be traced upward through all gradations from unaltered rock, rotten rock, and subsoil to the true soil on top. Such soils that have been derived from the rock directly beneath are described as having been formed in situ or in place. They are practically lacking in this region. Soils that have been carried from their place of origin and deposited elsewhere are called transported soils. The agents of transport are rain, streams, wind, and glaciers. In Connecticut the soils are predominantly transported, and glaciers have been the chief agents.

SOIL FACTORS.

There are certain factors or properties which give to a soil its character and determine its value.

Composition. Certain chemical elements are needed by growing vegetation and if lacking the full development of a plant is hindered. But almost every soil contains all the necessary elements in varying amounts and combinations. This is probably the least disturbing soil factor, at any rate glacial action controls it less than any of the factors.

Texture. The texture of the soil (gravelly, sandy, loamy, clayey, loose, open, compact, or firm), determines its water holding capacity, the amount of plant food dissolved in a given time, the relative freedom of root penetration, and the aeration of the soil.

Nature of Bed Rock. Soils formed in place have certain qualities derived from the parent ledge, but transported soils have no definite relation to the rock surface beneath, except where the distance of transportation is slight or where one kind of rock persists over a large area.

Position. The topographic position of a soil is an important factor. A soil that is constantly flooded becomes so clogged with water that it can produce only a specialized type of vegetation.

Sluggish drainage in enclosed basins, on flats so level that surface waters can scarcely move across them, or directly above an impervious clay layer may spoil an otherwise good soil. Neither is soil productive when too well drained. For this reason some terraces are less productive than the neighboring flood plain. Soil on a steep slope, where the loss of water is great on account of the excessive run-off, is more likely to be removed by erosion than soil on a more gentle incline. The run-off is at a minimum or zero on a level. Soil on slopes is subject to loss of water and also to rapid removal by rainwash. The direction and degree of slope are responsible in a measure for the temperature of the soil.

Depth. A thin soil resting on rock has distinct disadvantages. Root growth is restricted, extremes of temperature and moisture are frequent, plant food is small in amount, and entire loss by erosion is possible.

Humus. The partially decayed organic matter in the soil, known as humus, is valuable in several ways. It is a texture modifier, improving both coarse sandy and heavy clay soils; it is a good water holder; it contains valuable plant food, particularly nitrogen; and is of service in other ways.

No one of these factors operates to the exclusion of the others, but all combine and interact to a greater or less degree. Much variety in the soils of even a small area results. There is a close relation between geologic features and soil values.

COMPARATIVE VALUE OF TILL AND STRATIFIED DRIFT.

For agricultural soil, till is better than stratified drift in the following respects.

(a) Till is finer grained, contains more silt and clay; therefore it holds moisture better than stratified drift, and yields to solution more readily.

(b) Till is made up of mechanically derived material ground small during transportation with a minimum of loss by solution. Stratified drift, on the other hand, by being carried in the water so that it is partly decomposed, is robbed of material useful to plants.

(c) Till in some ways occupies a better position. Its location, mainly on uplands and hill slopes, causes better drainage — fewer

swamps are found on a slope than on a flat. Wherever it has the advantage of position and slope, till excels stratified drift.

But till may also be poorer than stratified drift as a soil maker.

In many places till is so stony that its agricultural value is impaired or spoiled. The presence of large-sized stones and bowlders lessens the workable acreage, and their increase in number causes agriculture to become more and more of a problem, until in many instances a field has no value except for pasturage. From some land, bowlders have been removed or used for fences, a solution for the problem involving an amount of labor and energy which could have brought about many other and more important improvements. (See Pl. VIII, *B*). Fields of stratified drift have few bowlders.

The compact texture of some till hinders cultivation and also prevents a proper spread of roots. The very fine texture of till though insuring good water-holding power may because of that very fact be a disadvantage where the soils are naturally poorly drained; and too much water makes soil cold and late.

Although a slope insures proper drainage, it may aid erosion to the detriment of the soil. Such slopes are more frequent in till than stratified drift.

This area has not only more outcrops of ledge in till than in stratified drift, but in many places the till covering is only a few inches or a foot thick.

The good qualities that till usually possesses may be spoiled by admixture with local material, much of which is sandstone yielding a poor soil. This feature is more likely to be of importance where till is thin.

VARIETY OF SOILS.

Although the general characteristics of till soil are different from those of stratified drift, it does not follow that all the soils on till, for instance, are alike. In fact, even a small farm, whether wholly on till or wholly on stratified drift, may have a great variety of soils.

A knowledge of the origin and characteristics of the two deposits is the foundation from which more detailed and definite explanations can be made. Glacial geology will explain part,

and other lines of study — some geologic and some not — will be needed to effect the solution; many local influences necessitate separate consideration for each problem.

Two illustrations are given here to help make clear how easily a considerable variety in a single region of small dimensions can

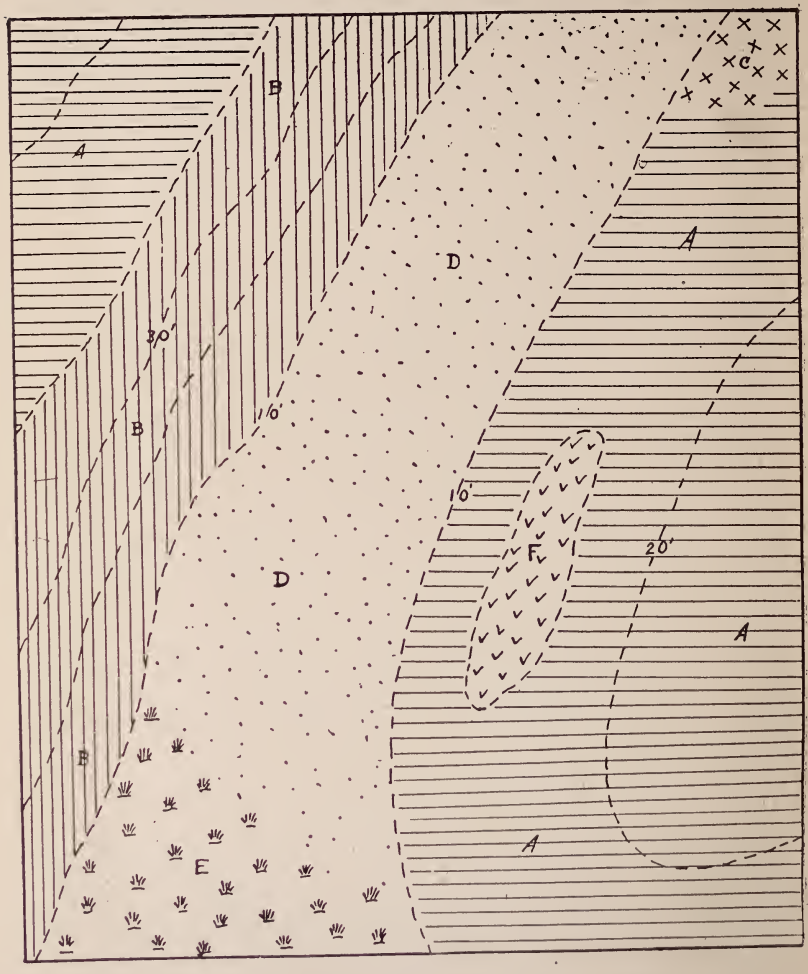


FIG. 16. Diagram showing soil variety in till in type locality. Width of map 500 yards. Contour interval 10 feet. The symbols and letters have the following meaning: *A*, Gentle slopes in upland covered with unmodified till; *B*, Steep slopes covered with modified till; *C*, Bowlders; *D*, Lowland with covering of fine materials washed from slopes; *E*, Swamp; *F*, Rise with normal till covering sandstone ledge.

exist, and how the various soil factors are related to the situation. The instances cited are a composite of actual conditions seen in this area and will serve to show how the subject may be approached.

A. Variety in Till (see fig. 16).

Since this locality is in the till belt the general features of that material will be expected — the fine loamy or claylike texture, with a certain amount of stones and larger rock fragments and some large bowlders. But besides this, close examination reveals six different kinds of soil, the result of local variations of till and modification of the original till deposit.

The flat or gentle sloped uplands are covered with unmodified till, fine-textured and somewhat stony. In the northeast part is a small spot freely sprinkled with large bowlders. The steeper slopes are covered with what can be called modified till, the result of increased slope, in consequence of which the rainfall has gained sufficient velocity to wash away much of the finer part of till, leaving behind large stones and fragments. Hence, this part of till has lost quality and is found to be very freely sprinkled with stones. The finer material washed from the slope has been spread out and deposited in the lowest part of the locality, making a fine-textured, even soil of excellent quality and free from stones, but it is not so thick everywhere but that the plow will occasionally throw out one of the stones from the till below. In the southern part of this flat the drainage is so poor that a swamp has developed. The elongated rise of ground in the midst of the normal till is a spot where sandstone ledge is very near the surface; in consequence, the till soil is not only thin but has had its quality impaired by admixture of sandy material from the parent ledge locally scraped up by the glacier. The contacts between the soil types are nowhere absolutely sharp.

B. Variety in Stratified Drift (see fig. 17).

Here the topography is different from that of till — two flats at different levels separated by a rather steep terrace front. Since this locality is assumed as being in stratified drift, different grades of sands and possibly gravel, depending on the velocity of the streams that carried and deposited the material, will be expected.

The main part of the lower flat is a fine sandy soil of good quality; but through the midst of it is a broad strip of gravel, marking the position of a swifter flowing current; on the margin of this is finer gravel and coarse sand, and narrowing bands of

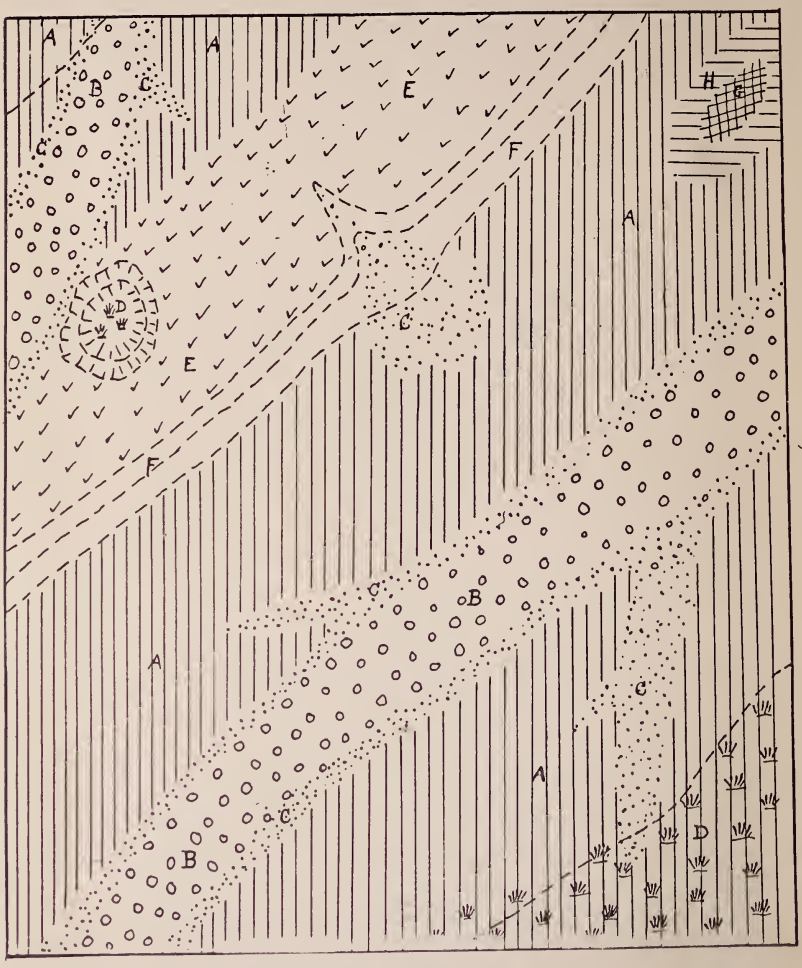


Fig. 17. Diagram showing soil variety in stratified drift in type locality. Width of map 500 yards. Contour interval 10 feet. The symbols and letters have the following meaning: *A*, Flat covered with fine sandy, good soil; *B*, Gravel; *C*, Fine gravel and coarse sand; *D*, Swamp; *E*, Texture like *A* but with lower water table; *F*, Terrace front; *G*, Till not completely covered with stratified drift; *H*, Area influenced by till.

the same material branch off from the main current portion for varying distances. More of the coarse sand and fine gravel was washed from the upper terrace and spread on the lower flat when the small gorge was cut. In the southeast part, a swamp spoils some little acreage. On the upper flat is a similar fine sandy soil with a band of gravel and coarse sand cutting across it. The circular depression is a kettle hole with rather steep sides and a swampy bottom. That part of the terrace designated by v's is similar in texture to the main part of the flat, but the water table is so much lower that the soil can stand but little drought, and its cropping value is markedly lowered. The terrace front is too steep for profitable cultivation, as are also the sides of the kettle hole. A spot of till is shown which is not completely covered by stratified drift. Its influence extends for some little distance in every direction, for although stratified drift is immediately next to it, till is directly below and controls the crop just as a clayey subsoil would.

Many local features in any restricted region will give more variety than is outlined in these two illustrations; or, again, only a part of such conditions may obtain and thus cause less variability.

RECLAMATION.

Man is constantly modifying his environment. The farmer nearly always has to do something to his soil before he can expect returns. A field may have to be cleared of stumps or stones, or fertilizers of several kind may have to be added. One field of endeavor, however, will bring in thoroughly adequate results for the time and money expended, and that is reclamation. Soils may be reclaimed if they are too dry or too wet — reclamation is reducing extreme to mean conditions. This is less needed on a large scale in Connecticut, perhaps, but there is hardly a farm that has not some field that would be improved by addition of a little water during the active growing season; and often there are natural means of irrigation close at hand. The reverse, also, is true. There are few farms in Connecticut that do not have

some lost land due to the presence of swamp. A glacial region usually has abundant swamp spots, and Connecticut is no exception in this respect. It has been found cheaper to drain swamp-land and make it fit for a good crop than to irrigate arid land, acre for acre, and it would probably be less laborious to drain a swamp than to clear a stony field.

DATE DUE

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Bedrock Map of the New Haven Region

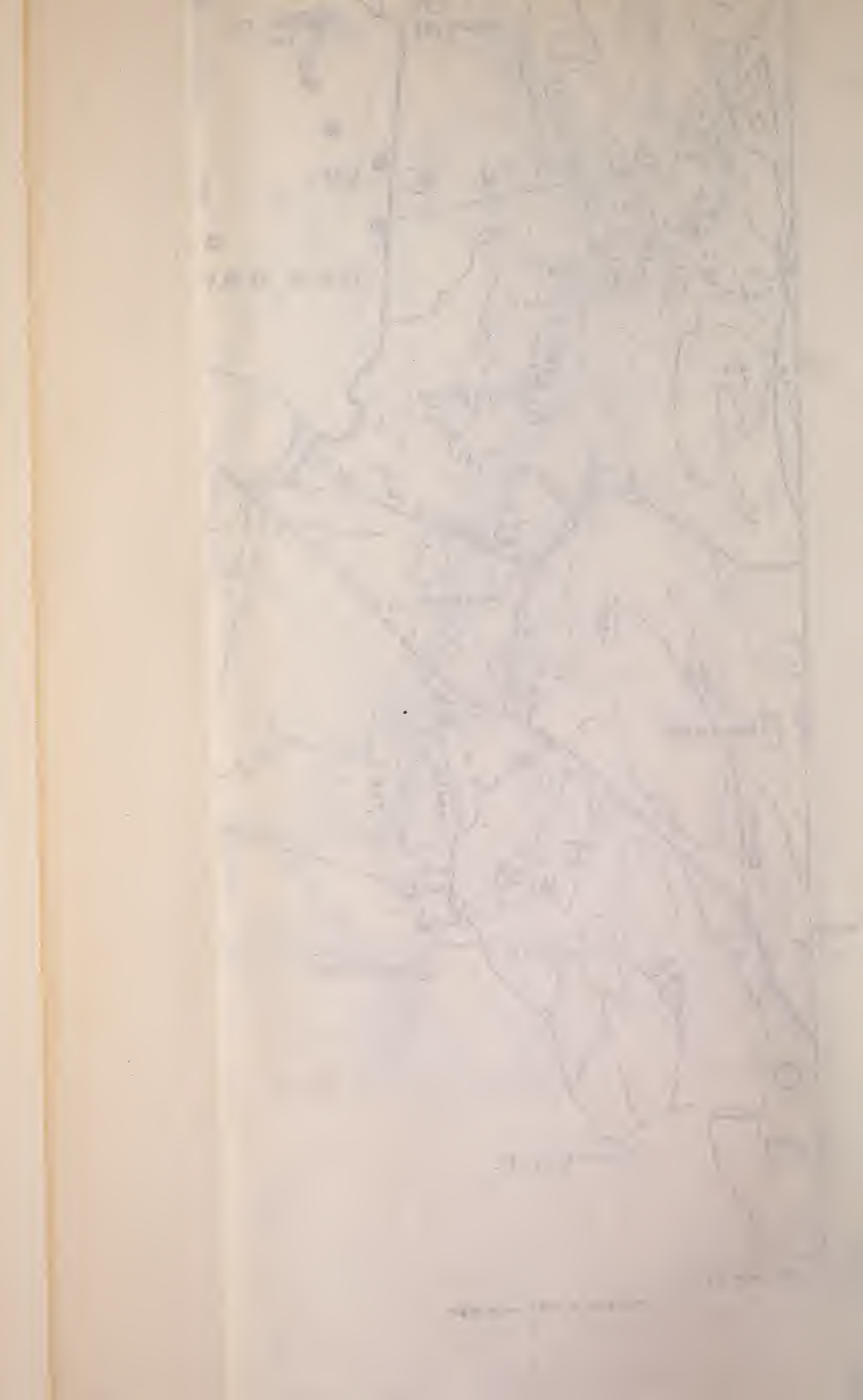
- ·-·-· = Bed Rock at Surface.
- ≈ = Nearly Continous outcrop of Bed Rock.
- × = Bed Rock 5 ft. or less from surface.
- ○ = Bed Rock 6-20 ft. from surface.
- ⊗ = Bed Rock 21-60 ft. from surface.
- □ = Bed Rock 61-100 ft. from surface.
- ⊠ = Bed Rock-more than 60 ft. from surface.
- △ = Bed Rock-more than 100 ft. from surface.
- ▲ = Bed Rock-more than 200 ft. from surface.

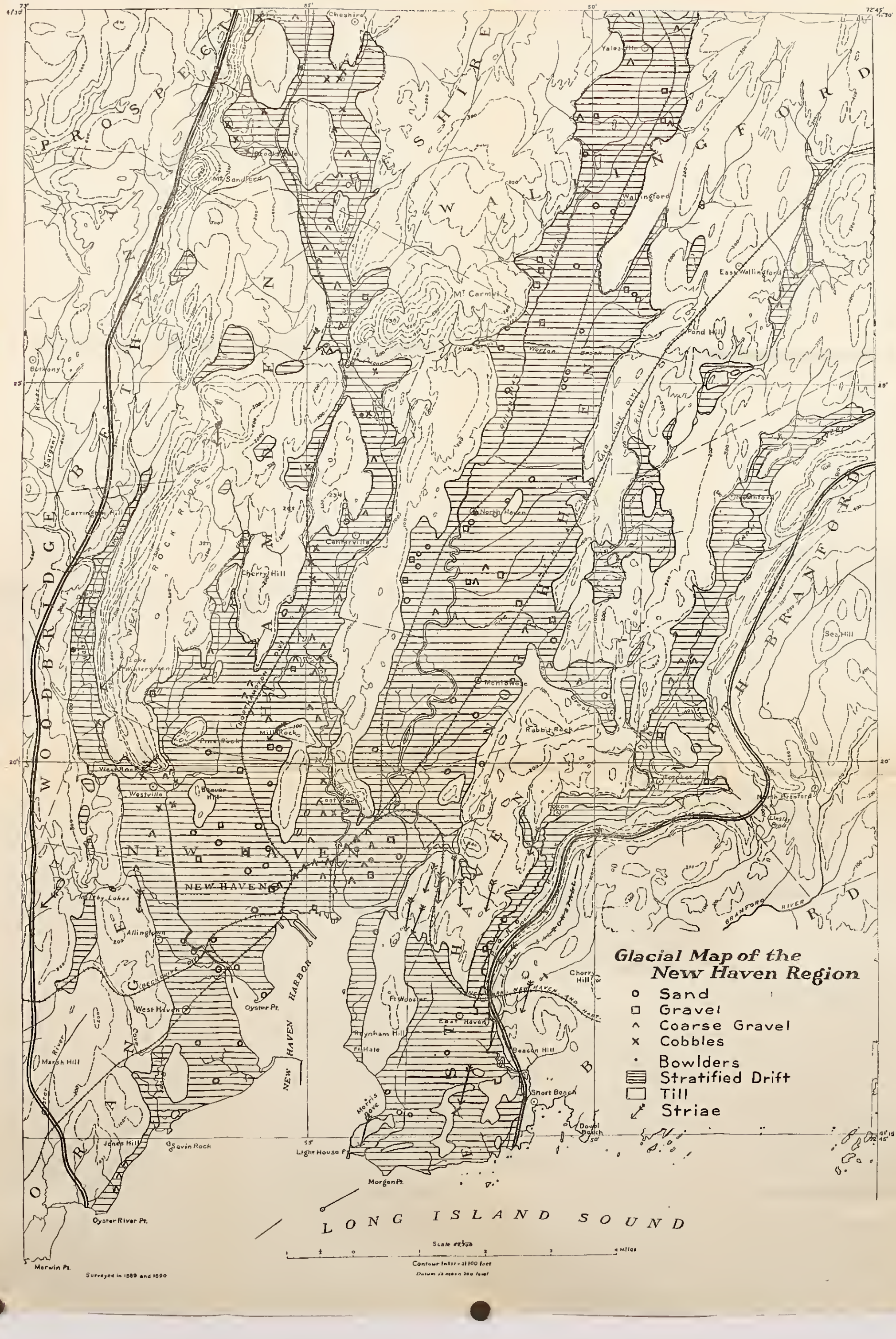
Scale of 1/62500

Contour Interval 100 feet

Datum is mean Sea level.

Surveyed in 1889 and 1890.




Cheshire
Yalesville
Wallingford
East Wallingford
Mt Carmel
Pond Hill
Mt Sandford
Prospect
Bethany
Sargent River
Carrington Hill
Centerville
Cherry Hill
North Haven
Woodmont
Sea Hill
Lake Whitney
Montowese
Rabbit Rock
Mill Rock
Pine Rock
Westville
Beaver Hill
East Rock
Foxon
North Branford
Linsley Pond
Branford River
Allingtown
West Haven
Oyster Pt.
Ft Wooster
Cherry Hill
Rogers Lake
Reynham Hill
Ft Hale
Beacon Hill
Short Beach
Double Beach
Marsh Hill
Morris Cove
Jones Hill
Savin Rock
Light House Pt.
Morgan Pt.
Oyster River Pt.
Marwin Pt.
WOOSTER RANGE
PROSPECT RANGE
BETHANY RANGE
SOUTHINGTON WALLINGFORD RANGE
GUILFORD RANGE
HANOVER RANGE
BRANFORD RANGE
WEST ROCK RIDGE
NEW HAVEN
NEW HAVEN HARBOR
LONG ISLAND SOUND
Glacial Map of the New Haven Region
Sand
Gravel
Coarse Gravel
Cobbles
Bowlders
Stratified Drift
Till
Striae
Scale
Contour Interval 100 feet
Datum is mean Sea level
Surveyed in 1889 and 1890

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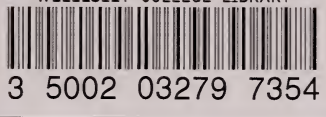

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Ward, Freeman, b. 1879.

The Quaternary geology of the New Haven region,